⬧EPA

United States Environmental Protection Agency
Office of Enforcement and Compliance Assurance
Office of Criminal Enforcement, Forensics and Training

National Enforcement Investigations Center

NEIC

NEICRP1899X01

PRODUCED WATER HYDROGEN SULFIDE HAZARD

United States of America v. Aghorn Operating Inc., Trent Day, and Kodak Roustabout Inc. 7:22-cr-00049-DC
Aghorn Energy
Ector County, Texas
NEIC Project No.: RP1899
CID Case No. 0606-M595

JOE LOWRY Digitally signed by JOE LOWRY
Date: 2022.04.20 08:56:30
-06'00'

Joe H. Lowry, Ph.D.
March 20, 2022

Prepared for:
Christopher J. Costantini, Senior Trial Attorney
Environmental Crimes Section
Environment & Natural Resources Division
United States Department of Justice

Matthew Myles, Special Agent
EPA Criminal Investigation Division
Houston Resident Office
1919 Smith Street, Suite 925
Houston, Texas 77002

United States Environmental Protection Agency
Office of Enforcement and Compliance Assurance
Office of Criminal Enforcement, Forensics and Training
National Enforcement Investigations Center
P.O. Box 25227
Building 25, Denver Federal Center
Denver, Colorado 80225

Exhibit 1

TABLE OF CONTENTS

TABLES

FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

ACGIH   American Conference of Governmental Industrial Hygienists
ATSDR   Agency for Toxic Substances and Disease Registry
EPA   U.S. Environmental Protection Agency
NEIC   National Enforcement Investigations Center
NFPA   National Fire Protection Association
NIOSH   National Institute for Occupational Safety and Health
OSHA   Occupational Safety and Health Administration

CAA   Clean Air Act
CFR   Code of Federal Regulations
GDC   General Duty Clause

MRL   Minimum Risk Level
TLV   Threshold Limit Value
TWA   Time Weighted Average
STEL   Short Term Exposure Limit
IDLH   Immediately Dangerous to Life and Health

n moles
A area
V volume
P pressure
R gas constant equal to 0.082057 liter atmosphere per mole Kelvin
T temperature
$°F$ temperature in degrees Fahrenheit
$°C$ temperature in degrees Celsius
K temperature in Kelvin
k_H Henry's law constant
K_{a1} first proton dissociation constant for hydrogen sulfide
K_{a2} second proton dissociation constant for hydrogen sulfide
atm   atmosphere
bbl   barrel
g gram
gal   gallon
L liter
M molar equal to mole per liter
ppm   part per million
ppmv   part per million by volume
mg/L   milligrams per liter
x distance

I. PERSONAL BACKGROUND

I.1.   Report Information

The following is a list of the items concerning the preparation of the expert report:

1) This expert report contains my opinions, conclusions, and the reasons, therefor.

2) I will provide upon request all materials relied upon and work papers created in connection with this report, with exception of any privileged materials, such as attorney work product.

3) I received no special compensation for the preparation of this report outside of my regular salary received as a U.S. Environmental Protection Agency (EPA) employee.

4) I have testified twice within the preceding 4 years as an expert during legal proceedings.

5) The information I relied on in forming the opinions expressed in this report are footnoted and available as electronic files. In addition to this footnoted information, I also considered the hundreds of electronic files forwarded on various dates as attachments to electronic mail from Senior Trial Attorney Christopher Costantini and the many more electronic files placed in a Box, Inc. file sharing account managed by the United States Department of Justice's Justice Enterprise File Sharing System. Replicates of various documents were included in the electronic files.

The opinions expressed in this report are my own and are based on the data and facts available to me at the time of writing. If additional relevant or pertinent information becomes available, I may supplement the discussion and findings in my report.

I.2.   Expertise

This section of my report sets forth portions of my background, education, training, and experience relevant to the substantive issues I address in this report. My curriculum vitae is attached as **Appendix A**.

I have more than 43 years of experience in the application of chemistry to environmental problems. I received a B.Sc. in Chemistry from the Western Michigan University, an M.Sc. in Water Resources Science from the University of Michigan, and a Ph.D. in Environmental Health Sciences from the University of Michigan. During my graduate studies, my emphasis was on environmental chemistry.

I have been employed by the EPA National Enforcement Investigation Center (NEIC) since 1978. During my employment, I have had the opportunity to work on a wide range of chemistry issues related to environmental enforcement, including the properties of substances that pose hazards. The hazardous properties of substances in materials from the oil and gas industry concerning incidents involving injuries and fatalities were important to my work for, *U.S. v. Custom Carbon Processing, Inc., Peter Margiotta, and Mark Hurst, U.S.* v. *KTX Limited and KTX Properties, Inc., U.S.* v. *Port Arthur Chemical Company and Environmental Services,* State *of Ohio* v. *United Oil Recovery Services, Inc. and David Weber,* and *U.S.* v. *Texas Oil and Gathering, Inc.*

II. SUMMARY OF CONCLUSIONS

A. The release of gas from the produced water at the Aghorn Energy facility in Ector County, Texas, which created a lethal atmosphere of hydrogen sulfide on October 26, 2019, that resulted in the death of Natalee and Jacob Dean, sadly illustrates the reason hydrogen sulfide is considered an extremely hazardous substance by EPA.

B. Hydrogen sulfide, a major contaminant of the produced water at the Aghorn Energy facility in Ector County, Texas, is readily released from the water to the air at atmospheric pressure and ambient temperature. This property can pose an inhalation hazard to persons in the vicinity of the produced water.

C. The gas released from the produced water was hydrogen sulfide, an extremely hazardous substance, into the ambient air above health-based standards.

III.   EXTREMELY HAZARDOUS SUBSTANCE

III.1. Background

The Clean Air Act was amended by Congress in 1990 adding Section 112(r). This section requires owners and operators of stationary sources to implement chemical accident prevention at facilities using extremely hazardous substances. Specifically, Section 112(r)(1) states: "(r) Prevention of Accidental Releases (1) Purpose and General Duty - It shall be the objective of the regulations and programs authorized under this subsection to prevent the accidental release and to minimize the consequences of any such release of any substance listed pursuant to paragraph (3) or any other extremely hazardous substance. The owners and operators of stationary sources producing, processing, handling or storing such substances have a general duty, in the same manner and to the same extent as section 654, title 29 of the United States Code, to identify hazards which may result from such releases using appropriate hazard assessment techniques, to design

NEICRP1899X01

Lowry Expert Report
Page 6 of 44

Aghorn Energy
Ector County, Texas

AGH-OPER-0049353

and maintain a safe facility taking such steps as are necessary to prevent releases, and to minimize the consequences of accidental releases which do occur."[1]

Hydrogen sulfide was one of the 16 extremely hazardous substances listed by Congress in paragraph 3 of 1990 Clean Air Act amendment.   EPA developed regulations including lists pursuant to paragraph 3 and these lists include hydrogen sulfide. As provided above, the general duty clause applies to any extremely hazardous substance, even if it is not listed pursuant to paragraph 3. Further, the Senate said, "the release of any substance which causes death or serious injury or which causes substantial property damage would create a presumption that such substance is extremely hazardous."[2] The deaths of Natalee and Jacob Dean unfortunately evidence the Senate's concern about the extreme hazard posed by substances such as hydrogen sulfide.

III.2.   Produced Water

The Foster D Section 8 waterflood station received produced water from various adjacent leases into storage tanks and the produced water under high pressure was delivered to various wells and injected into the Grayburg-San Andres formation. [3, 4] Produced water is water trapped in underground formations that is brought to the surface along with oil or gas. Produced water often is highly saline generally containing a mix of mineral salts including chloride, bicarbonate/carbonate, and sulfate salts of sodium, calcium, and magnesium.[5] Produced water from the Foster Field has been reported to have a total dissolved solids content of about 37,000 milligrams per liter (mg/L) to 67,000 mg/L, most of which is sodium chloride.[6] A February 27, 2020 electronic mail from Maria Thompson Poirot to Diana Lundelius states the BioTech Performance Monitoring Overview report reflects data for the produced water received at the waterflood station from all the leases.[7] This BioTech report is contained in a document identified

---

[1] Compilation of Selected Acts within the Jurisdiction of the Committee on Commerce, Environmental Law. 104th Congress, 1st Session, Committee Print 104-F, U.S. Government Printing Office, Washington, 1995, p.85.
[2] Senate Committee on Environment and Public Works, Clean Air Act Amendments of 1989, Senate Report No. 228, 101st Congress, 1st Session 211, 1989, p 211.
[3] Letter from Marla Thompson Poirot, Foley & Lardner LLP, to Diana Lundelius, USEPA Region 6, dated January 24, 2020. AGH_0001880.
[4] Railroad Commission of Texas, Permit, AGH-OPER-0003086 to AGH-OPER-0003102. AGH-OPER-0003104 to AGH-OPER-0003141. AGH-OPER-0003143 to AGH-OPER-0003175.
[5] Neff J., Lee K., DeBlois E.M. (2011) Produced Water: Overview of Composition, Fates, and Effects. In: Lee K., Neff J. (eds) Produced Water. Springer, New York, NY.
https://www.researchgate.net/publication/225911658_Produced_Water_Overview_of_Composition_Fates_and_Effe cts/link/02e7e530ce0d6b14e8000000/download
[6] Trentham, R.; Weinbrandt, R.; Robinson, W. (1997, May 28), An Integrated Study of the Grayburg/ San Andres Reservior, and South Cowden Fields, Ector County, Texas, Annual Technical Report, DE-FC22-94BC14982, Laguna Petroleum Corporation, Midland, Texas, DOE/BC/14982-14, Figure 8 and (1997, October 23) Figure 23.
[7] Electronic mail from Marla Thompson Poirot, Foley & Lardner LLP, to Diana Lundelius, USEPA Region 6, dated February 7, 2020. AGH_0003935

as "Exhibit "01DOC13" BioTech".[8] Consistently, the BioTech report shows the produced water handled at the Foster D facility had high salinity with a total dissolved solids content of about 45,000 mg/L, again most of which was sodium chloride[9].

Produced water also typically contains dissolved gas like carbon dioxide, methane, and hydrogen sulfide. The terms sour and sweet are used in the oil and gas industry to discern oil, gas, or water that contain significant amounts of hydrogen sulfide.[10] Hydrogen sulfide is an acid as it contains two dissociable hydrogen ions (protons). Acids commonly have a sour taste and hence the term "sour" is used. Hydrogen sulfide is a gas at ambient temperature and atmospheric pressure and is soluble in oil and water. At low concentrations in air, it has a characteristic rotten egg odor. Some of the dissolved hydrogen sulfide contained in produced water brought up from the subsurface under pressure can be released at the surface as pressure decreases. If a sudden pressure reduction occurs the gas release may be referred to as a flash. Carbon dioxide and hydrogen sulfide have molecular weights greater than air and hence at high concentrations could cause a gas release plume to hug the ground; however, water, which likely is near saturation in gas above the produced water, and methane have molecular weights smaller than air which would act counteractively.

The Texas Railroad Commission requires operators to measure the hydrogen sulfide concentration in the tank headspace. In a tank, some hydrogen sulfide in the produced water will partition from the water in the tank headspace. Tarver and Dasgupta state that west Texas storage tank vapor hydrogen sulfide can reach 140,000 part per million (ppm) to 180,000 ppm.[11] Cunningham reported gas from the Foster field contained 25,000 ppm hydrogen sulfide.[12] The Texas Railroad Commission website lists gas hydrogen sulfide concentrations for the Foster field as 9,180 ppm, 38,108 ppm, 67,744 ppm, and 107,476 ppm.[13] Aghorn Operating Inc., reported to the Texas Railroad Commission hydrogen sulfide concentrations of 96,000 ppm and 110,000 ppm at the Foster D facility. These hydrogen sulfide concentrations are extremely high. Consider, a concentration of 100,000 ppm is equal to 10 percent (%), while the atmosphere is typically

---

[8] Exhibit "01DOC13" BioTech, AGH_0002873 to AGH_0002889; AGH_0004600 to AGH_0004615
[9] Aghorn Operating Inc., - Additional EPA Information Request, (2020, February 13) BioTech Inc. Water Analysis. Performance Monitoring Overview. Aghorn Energy, Foster D Injection – Ector County, Texas. AGH_0002552 thru AGH_0002570 in an attached file to Christopher Costantini 11-14-20 electronic mail.
[10] Recommended Practice for Oil and Gas Producing and Gas Processing Plant Operations Involving Hydrogen Sulfide, API Recommended Practice 55 Second Edition, February 1995, Reaffirmed, January 2013, American Petroleum Institute, 1220 L Street, Northwest, Washington, D.C. AGH-OPER-0005063 to AGH-OPER-0005114 at AGH-OPER-0005109
[11] Tarver, G.; Dasgupta, P. Oil Field Hydrogen Sulfide in Texas: Emission Estimates and Fate, Environmental Science and Technology, 31, 3669-3676, 1997. AGH-OPER-0000760 to AGH-OPER-0000767.
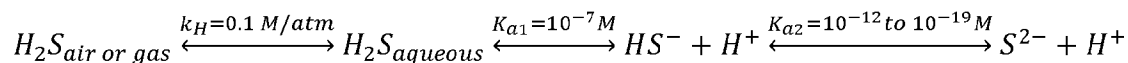[12] Cunningham, W. Hydrogen Sulfide in West Texas, Industrial and Engineering Chemistry, 42(1), 2238-2241. 1950.
[13] Texas RRC Hydrogen Sulfide (H2S) Fields and Concentrations Listing District 08. https://www.rrc.state.tx.us/oil-and-gas/research-and-statistics/field-data/hydrogen-sulfide-h2s/h2s-district-08/ and AGH-OPER-0009832 to AGH-OPER-0009876 at AGH-OPER-0009847.

approximately 78% nitrogen and 21% oxygen. The reported hydrogen sulfide concentrations are orders of magnitude above health-based standards and generally fall within the flammability range for hydrogen sulfide.

The reduction of the solubility of a gas due to the presence of ionic species in solution is called "salting-out". The "salting-out" of hydrogen sulfide by sodium chloride in water has been measured and at the sodium chloride concentrations in the Foster D facility produced water the solubility of hydrogen sulfide would decrease by about 8%.[14] This means more hydrogen sulfide would partition from produced water into the tank headspace for the same concentration of hydrogen sulfide in a produced water of lower salinity.

III.3.   Hydrogen Sulfide Equilibria

Once the produced water is brought to the surface, various chemical equilibria favor partitioning of the hydrogen sulfide from the produced water to the air (atmosphere, tank headspace, etc). Generally mass transport from the water to the air is governed by diffusion and turbulence. Hydrogen sulfide partitions between the water (aqueous phase) and air or gas phase. Hydrogen sulfide can form ionized species in solutions of water. The following chemical reaction expression depicts this equilibrium partitioning where k_H is the equilibrium partitioning coefficient of hydrogen sulfide between air and water in units of molar per atmosphere (M/atm), K_{a1} is the first proton dissociation constant of hydrogen sulfide, and K_{a2} is the second proton dissociation constant.

$$H_2S_{air\ or\ gas} \xleftrightarrow{k_H=0.1\ M/atm} H_2S_{aqueous} \xleftrightarrow{K_{a1}=10^{-7}M} HS^- + H^+ \xleftrightarrow{K_{a2}=10^{-12}to\ 10^{-19}M} S^{2-} + H^+$$

In water, hydrogen sulfide can dissociate to a proton (H^+) and the hydrosulfide ion (HS^-). The hydrosulfide ion and can further dissociate to a proton and the sulfide ion (S^{2-}).[15] For produced water the mass transfer is toward the left; into the air. As hydrogen sulfide in the air or gas disperses, some hydrogen sulfide in the water transfers into the air, and some hydrosulfide ion protonates forming aqueous hydrogen sulfide. Hence, the ionized species act as a reservoir for hydrogen sulfide, effectively increasing the solubility in the aqueous phase.

The extent of the dissociation of hydrogen sulfide in water is pH dependent. The following equilibrium expression shows this pH dependence for the first proton dissociation, where the brackets indicate molar concentrations for the specified species.

---

[14] Suleimenov, O.; Krupp, R. Solubility of hydrogen sulfide in pure water and in NaCl solutions, from 20 to 320 °C and at saturation pressures. Geochima et Cosmochimca Acta 58(11), 2433-2444, 1994.
[15] "Dissociation Constants of Inorganic Acids and Bases," in CRC Handbook of Chemistry and Physics, 101st Edition (Internet Version 2020), John R. Rumble, ed., CRC Press/Taylor & Francis, Boca Raton, FL.

NEICRP1899X01

Lowry Expert Report
Page 9 of 44

Aghorn Energy
Ector County, Texas

AGH-OPER-0049356

$$K_{a1} = \frac{[H^+][HS^-]}{[H_2S]} = \frac{[10^{-pH}][HS^-]}{[H_2S]} = 10^{-7}\frac{mole}{L}$$

Rearranging the expression to solve for the hydrosulfide ion to hydrogen sulfide ratio helps to reveal, that at pH 7, the molar hydrosulfide ion concentration will equal the molar hydrogen sulfide concentration.

$$\frac{[HS^-]}{[H_2S]} = \frac{K_{a1}}{\left[10^{-pH}\frac{mole}{L}\right]} = \frac{10^{-7}\frac{mole}{L}}{\left[10^{-7}\frac{mole}{L}\right]} = 1$$

At pH below 7, hydrogen sulfide will predominate; at pH above 7, the hydrosulfide ion will predominate. A pH range of 6.5. to 7.5 has been reported for produced water in the Permian Basin.[16] Because the second proton dissociation constant to form the sulfide ion is so low, the sulfide ion would be present at insignificant amounts in produced water. However, the hydrosulfide ion will equal about 31.6% of the hydrogen sulfide concentration at pH 6.5 and about 316% of the hydrogen sulfide ion concentration at pH 7.5.

$$[HS^-] = \frac{(K_{a1})[H_2S]}{\left[10^{-pH}\frac{mole}{L}\right]} = \frac{\left(10^{-7}\frac{mole}{L}\right)[H_2S]}{\left[10^{-6.5}\frac{mole}{L}\right]} = (10^{-0.5})[H_2S] = (0.316)[H_2S]$$

$$[HS^-] = \frac{\left(10^{-7}\frac{mole}{L}\right)[H_2S]}{\left[10^{-7.5}\frac{mole}{L}\right]} = (10^{0.5})[H_2S] = (3.16)[H_2S]$$

Hence the solubility of hydrogen sulfide species increases significantly at higher pH.

For aqueous solutions, the equilibrium partitioning of hydrogen sulfide to air has been measured and is often referred to a Henry's Law constant. Henry's Law constant is often expressed as the quotient of the aqueous concentration ($[H_2S]_{aqueous}$) of the compound and its partial pressure (p_{gas}), commonly given in units of molar per atmosphere (M/atm).

$$k_H = \frac{[H_2S]_{aqueous}}{p_{gas}}$$

---

[16] Carpenter, C. (2019, February 13). Fit-for-Purpose Water Treatment in Permian Shale: Field Data, Laboratory Data, and Comprehensive Overview, Society of Petroleum Engineers from "Fit-for-Purpose Water Treatment in Permian Shale: Field Data, Laboratory Data, and Comprehensive Overview," by John Walsh, SPE, CETCO Energy Services, and Ramesh Sharma, SPE, ConocoPhillips, prepared for the 2018 SPE Annual Technical Conference and Exhibition, Dallas, 24–26 September. https://pubs.spe.org/en/ogf/ogf-article-detail/?art=5097

The temperature dependence of the constant is given by the following.

$$k_H^T = (k_H^{298\,K})exp\left(\left(\frac{d(\ln k_H)}{d(1/T)}\right)\left(\frac{1}{T} - \frac{1}{298.15\,K}\right)\right)$$

Sanders[17] and National Institute of Standards and Technology (NIST)[18] give a Henry's Law constant (k_H) at 25 degrees Celsius (°C) of 0.1 molar per atmosphere (M/atm) with a temperature coefficient of 2100 for hydrogen sulfide. The Henry's Law constant at 60 degrees Fahrenheit (°F) (15.56 °C, 288.71 Kelvin (K)) would be 0.1259 M/atm. Hence, the solubility of hydrogen sulfide in water increases at lower temperature.

$$k_H^T = \left(0.1\frac{M}{atm}\right)exp\left((2100)\left(\frac{1}{288.71\,K} - \frac{1}{298.15\,K}\right)\right) = 0.1259\frac{M}{atm}$$

Inverting this value to give a ratio of the air concentration to the water concentration and converting to more colloquial units of part per million by volume (ppmv) for the air concentration and part per million (ppm) for the water concentration, gives 233 ppmv per ppm.

$$K_{AW} = \frac{1}{k_H} = \frac{1}{0.1259\frac{M}{atm}} = \frac{\left(1,000,000\frac{ppmv}{atm}\right)\left(1\frac{mg/L}{ppm}\right)}{\left(0.1259\frac{mole}{L\,atm}\right)\left(34.08\frac{g}{mole}\right)\left(1000\frac{mg}{g}\right)} = 233\frac{ppmv}{ppm}$$

Consideration of the Foster D produced water "salting-out" effect would increase K_{AW} by about 8% to 252 ppmv per ppm.

III.4.   Part Per Million In Air Versus Part Per Million In Water

Hydrogen sulfide concentrations in air and water are often given as part per million (ppm). A part per million in water is equal to a milligram per liter. At 4 °C, water has a mass density of about 1000 grams per liter. One millionth of a gram is equal to a microgram. A milligram per 1000 grams is equal to a microgram per gram and hence one part in a million parts on a weight basis.

$$\frac{(1\,milligram\,H_2S)\left(1000\frac{microgram}{milligram}\right)}{(1\,Liter)\left(1000\frac{gram}{Liter}\right)} \times 1\frac{ppm}{\frac{microgram}{gram}} = 1\,ppm$$

---

[17] Sander, R. Compilation of Henry's law constants (version 4.0) for water as solvent. Atmospheric Chemistry and Physics, 15, 4399-4981, 2015. https://acp.copernicus.org/articles/15/4399/2015/acp-15-4399-2015.pdf
[18] Sander, R. "Henry's Law Constants" in NIST Chemistry WebBook, NIST Standard Reference Database Number 69, Eds. P.J. Linstrom and W.G. Mallard, National Institute of Standards and Technology, Gaithersburg MD, 20899, https://doi.org/10.18434/T4D303, (retrieved December 9, 2020).

A part per million in air is on a volume basis and hence a mole basis. The Ideal gas law shows that the gas volume (V) is directly proportional to the moles (n) of gas, where P is the pressure, T is the temperature, and R is the gas constant.

$$PV = nRT$$

Rearranging the Ideal gas law equation to solve for the molar volume and substituting a pressure of 1 atmosphere and a temperature of 60 °F (288.71 K) gives a molar volume of 23.96 liter per mole.

$$molar\ volume = \frac{V}{n} = \frac{RT}{P} = \left(0.082057 \frac{liter\ atmosphere}{mole\ Kelvin}\right)\left(\frac{288.71\ Kelvin}{1\ atmosphere}\right) = 23.96 \frac{liter}{mole}$$

One millionth of 23.96 liter is equal to 0.00002396 liters or 23.96 microliters.

The reciprocal of the molar volume is the number density, which is in units of moles of a gas in a liter. A mole is equal to 6.023×10^{23} molecules.

$$number\ density = \frac{n}{V} = \frac{P}{RT} = \frac{1}{23.96 \frac{liter}{mole}} = 0.04221 \frac{mole}{liter}$$

One millionth of 0.04221 mole is equal to 0.00000004221 mole or 0.04221 micromole.

The molar concentration of water is 55.5 mole per liter, and hence, water has over 1300 times the number of molecules of air in a liter.

$$\frac{mass\ density\ of\ water}{molecular\ weight\ of\ water} = \frac{1000 \frac{g}{L}}{18.015 \frac{g}{mole}} = 55.51 \frac{mole}{L}$$

Therefore, a part per million of hydrogen sulfide in water is a much larger amount of hydrogen sulfide per liter than a part per million of hydrogen sulfide in air. For example, a milligram per liter of hydrogen sulfide in water is a part per million while 1 milligram per liter of hydrogen sulfide in air is about 695 part per million.

Hydrogen sulfide has a molecular weight of 34.081 gram per mole, hence 1 milligram of hydrogen sulfide per liter is 0.0000293 mole per liter.

$$n_{H_2S} = \frac{\left(1 \frac{milligram}{liter}\right)}{\left(34.081 \frac{gram}{mole}\right)\left(1000 \frac{milligram}{gram}\right)} = 0.0000293 \frac{mole}{liter} = 29.3 \frac{micromole}{liter}$$

A mass of 0.0000293 mole of hydrogen sulfide in a liter of air, which contains a total mass of 0.04221 moles per liter, would equal about 695 part per million.

$$\frac{\left(29.3 \frac{micromole}{liter}\right)}{\left(0.04221 \frac{mole}{liter}\right)} \times \left(1 \frac{ppm}{\frac{micromole}{mole}}\right) = 695 \; ppm$$

III.5.   Produced Water Hydrogen Sulfide Concentration

The Chemical Safety Board reported that produced water fed to the waterflood station contained 554 part per million of hydrogen sulfide.[19] This concentration can be found for a sample from the Gist B site in a document identified as "Exhibit "01DOC13" Catalyst Chemical (Excel Spreadsheet)".[20]

The BioTech report in a 5 page "Water Analysis" table under the "Dissolved Gas" main heading gives hydrogen sulfide (H_2S) concentrations for 131 samples with sample dates from August 2007 to October 2019.[21] As shown in Figure 1, the hydrogen sulfide concentrations ranged widely from 0 mg/L[22] to 3,615 mg/L. The average and median hydrogen sulfide concentrations for this data set are 657 mg/L and 650 mg/L, respectively.

---

[19] Hydrogen Sulfide Release at Aghorn Operating Waterflood Station, Odessa, Texas. Incident date October 26, 2019, No. 2020-01-1-TX, Factual Update, July 27, 2020, Chemical Safety and Hazard Investigation Board, page 1. https://www.csb.gov/assets/1/6/aghorn_factual_update_final_2020.07.27.pdf AGH-OPER-0014165 to AGH-OPER-0014171.

[20] Exhibit "01DOC13" Catalyst Chemicals (Excel Spreadsheet). AGH_0002890 to AGH_0002894.

[21] Exhibit "01DOC13" BioTech. AGH_0002873 to AGH_0002889; AGH_0004600 to AGH_0004615.

[22] For contaminant concentrations in water, 1 milligram per liter is equal to 1 part per million.
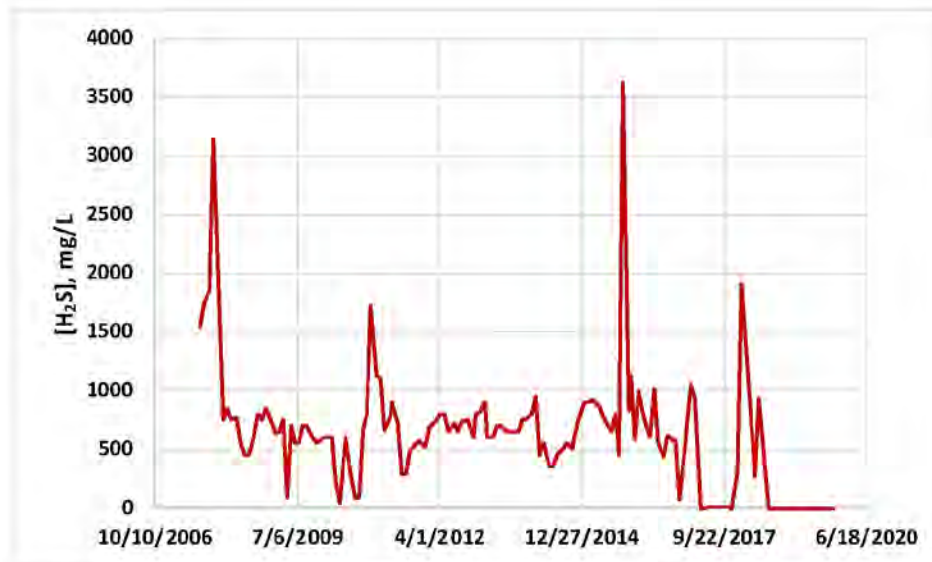
Figure 1 Hydrogen sulfide concentrations given in the BioTech report.

The Occupational Safety and Health Administration (OSHA) did collect produced water samples. However; the water was not analyzed rather the air that had been in contact with the water in the sample bottle was sampled and analyzed at the Salt Lake City laboratory. The sample bottles were 1-liter plastic bottles (Nalgene®). Such bottles are not considered gas tight. Anecdotal evidence to this fact is that the OSHA sampler reported the samples had a rotten eggs odor and pungent, and he doubled-bagged the samples because of the intensity of the odor.[23] Further, the OSHA laboratory reported that the samples were giving off a strong sulfur odor even when sealed in a Ziploc bag.[24] The OSHA air sampling reports give a sample collection date of November 1, 2019, an analyst receipt date of November 12, 2019, and analyses completion date of January 10, 2020. The measured hydrogen sulfide air concentrations were 62 ppm for the skim oil line sample, 173 ppm for the 5000-barrel overflow tank sample, and 134 ppm for the 3000-barrel suction tank sample.[25] The Henry's Law air/water partition coefficient for 60 °F of 233 ppmv/ppm calculated above provides that if the sampled air were in equilibrium with the water, the water concentrations would have been less than 1 ppm. However, these hydrogen sulfide air concentrations are minimal values because of considerable loss to the atmosphere and substantial oxidation over the time from collection to analysis. Because hydrogen sulfide is volatile and can be oxidized by oxygen, water samples are commonly preserved by raising the pH to greater than 9, to limit volatilization and the sulfide is precipitated as zinc sulfide to slow oxidation. With such preservation the sulfide is

---

[23] Michael Formoso interview, 6/10/2020, EPA CID Investigative Activity Report, AGH-OPER-0009749 to AGH-OPER-0009751.

[24] Daniel Johansen report, 1/10/20, AGH-OPER-0009323.

[25] Daniel Johansen interview, 6/18/2020, EPA CID Investigative Activity Report, AGH-OPER-0012408 to AGH-OPER-0012409.

considered stable for about 7 days.[26] After OSHA collected water samples, Aghorn collected samples at the same locations[27] but did not have them analyzed.[28]

"Certificates of Compliance Statewide Rule 36 Form H-9" for Aghorn Operating Inc., for the Foster D facility, dated 3/31/97 and 1/17/12, give hydrogen sulfide gas concentrations of 96,000 ppm and 110,000 ppm, respectively. Based on the Henry's Law air/water partition coefficient for 60 °F of 233 ppmv/ppm, water in equilibrium with these gas hydrogen sulfide concentrations would have hydrogen sulfide concentrations of 412 ppm and 472 ppm, respectively.

$$K_{AW} = \frac{C_{air}}{C_{water}} = 233\,\frac{ppmv}{ppm}$$

$$C_{water} = \frac{C_{air}}{K_{AW}} = \frac{96,000\,ppmv}{233\frac{ppmv}{ppm}} = 412\,ppm$$

$$C_{water} = \frac{C_{air}}{K_{AW}} = \frac{110,000\,ppmv}{233\frac{ppmv}{ppm}} = 472\,ppm$$

The hydrogen sulfide concentrations of 96,000 ppm and 110,000 ppm measured in the gas came from the produced water. The calculated Henry's law equilibrium hydrogen sulfide concentration in the produced water of 412 ppm and 472 ppm, are at equilibrium after the hydrogen sulfide partitioned from the water into air. Hence, the produced water entering the facility contained more than 412 ppm to 472 ppm hydrogen sulfide. When emissions from storage tanks are estimated, working loss is tank headspace that is displaced by the volume of water moving in and out of a tank. Emissions from tanks can also occur through breathing and flash loss. Breathing or standing loss is the expulsion of tank headspace because of daily changes in temperature and pressure.[29] Two Aghorn records give 15,880 barrels of produced water as incoming to the facility and 11,650 barrels of produced water as outgoing from the facility on October 26, 2019.[30, 31] A working loss volume equal to the produced water volume of 11,650 barrels and 15,880 barrels at

[26] 40 Code of Federal Regulations (CFR) § 136.3 Table II.
[27] Electronic mail from Darrell Corzine, Kelly, Morgan, Dennis, Corzine, & Hansen, P.C., to William Hougland, U.S. Chemical Safety and Hazard Investigation Board, dated November 1, 2019. AGH_0000218
[28] Letter from Darrell Corzine, Kelly, Morgan, Dennis, Corzine, & Hansen, P.C., to William Hougland, U.S. Chemical Safety and Hazard Investigation Board, dated November 22, 2019. AGH_0000992 to AGH_0001002 at AGH_0001000.
[29] Volume II. Chapter 10 Preferred and Alternative Methods for Estimating Air Emissions from Oil and Gas Field Production and Processing Operations, Eastern Research Group, Inc., Point Sources Committee Emission Inventory Improvement Program, September 1999, p 10.2-14. https://www.epa.gov/sites/production/files/2015-08/documents/ii10.pdf.
[30] Exhibit "01DOC15" October 2019, AGH_0003207 to AGH_0003238 at AGH_0003213.
[31] Exhibit "01DOC14", AGH_0002867 to AGH_0002872 at AGH_0002872

concentrations of 96,000 ppm (0.096 atmosphere) and 110,000 ppm (0.11 atmosphere) gives 564 pounds to 646 pounds and 769 pounds to 881 pounds, respectively. These masses are calculated by starting with the ideal gas equation where P is pressure, V is volume, and T is temperature in Kelvin, and rearranging to solve for n, the moles of gas,

$$PV = nRT$$

$$n = \frac{PV}{RT}$$

where the temperature was taken as 60 °F, which is equal to 288.71 Kelvin (T), and the gas constant (R) equal to 0.082057 liter atmosphere per mole Kelvin (L atm mol^{-1} K^{-1}).

$$n = \frac{(0.096\ atm)(11{,}650\ bbl)\left(42\frac{gal}{bbl}\right)\left(3.78541\frac{L}{gal}\right)\left(34.08\frac{g}{mol}\right)}{\left(0.082057\frac{L\ atm}{mol\ K}\right)(288.71K)\left(453.59\frac{g}{lb}\right)} = 563.9\ lb$$

$$n = \frac{(0.11\ atm)(11{,}650\ bbl)\left(42\frac{gal}{bbl}\right)\left(3.78541\frac{L}{gal}\right)\left(34.08\frac{g}{mol}\right)}{\left(0.082057\frac{L\ atm}{mol\ K}\right)(288.71K)\left(453.59\frac{g}{lb}\right)} = 646.2\ lb$$

$$n = \frac{(0.096\ atm)(15{,}880\ bbl)\left(42\frac{gal}{bbl}\right)\left(3.78541\frac{L}{gal}\right)\left(34.08\frac{g}{mol}\right)}{\left(0.082057\frac{L\ atm}{mol\ K}\right)(288.71K)\left(453.59\frac{g}{lb}\right)} = 768.7\ lb$$

$$n = \frac{(0.11\ atm)(15{,}880\ bbl)\left(42\frac{gal}{bbl}\right)\left(3.78541\frac{L}{gal}\right)\left(34.08\frac{g}{mol}\right)}{\left(0.082057\frac{L\ atm}{mol\ K}\right)(288.71K)\left(453.59\frac{g}{lb}\right)} = 880.8\ lb$$

With this then, the produced water volume of 11,650 barrels would have contained 2246 pounds (1682 pounds plus 564 pounds) to 2618 pounds (1972 pounds plus 646 pounds) of hydrogen sulfide. The estimated initial concentration of hydrogen sulfide in the produced water would be 550 ppm to 641 ppm.

$$C_{water}^{H_2S} = \frac{(2246\ lb)\left(453.59\frac{g}{lb}\right)\left(1000\frac{mg}{g}\right)}{(11{,}650\ bbl)\left(42\frac{gal}{bb}\right)\left(3.78541\frac{L}{gal}\right)} = 550\frac{mg}{L}$$

$$C_{water}^{H_2S} = \frac{(2618\ lb)\left(453.59\frac{g}{lb}\right)\left(1000\frac{mg}{g}\right)}{(11{,}650\ bbl)\left(42\frac{gal}{bb}\right)\left(3.78541\frac{L}{gal}\right)} = 641\frac{mg}{L}$$

These estimated hydrogen sulfide concentrations closely approximate the average and median concentrations of 657 mg/L and 650 mg/L, respectively, calculated from the 131 measured values, provided in the BioTech report for dissolved hydrogen sulfide gas in the produced water received at the facility.

III.6.   Produced Water Total Sulfide Concentration

As discussed in the equilibria section, if the pH of the produced water were 7, the hydrosulfide ion concentration would equal the hydrogen sulfide concentration. At pH 6.5, the hydrosulfide ion would be 31.6% of the hydrogen sulfide concentration and at pH 7.5, the hydrosulfide ion concentration would be 316% of the hydrogen sulfide concentration. Hence, at pH 6.5, 7, and 7.5, the hydrosulfide ion concentration would equal 169 mg/L to 197 mg/L, 534 mg/L to 622 mg/L, and 1688 mg/L to 1967 mg/L, respectively, when the hydrogen sulfide concentration was 550 mg/L to 641 mg/L.

$$C_{water}^{HS^-} = \frac{(K_{a1})\left(C_{water}^{H_2S}\right)\left(33.07\frac{g\,HS^-}{mole}\right)}{\left[10^{-pH}\frac{mole}{liter}\right]\left(34.08\frac{g\,H_2S}{mole}\right)} = \frac{\left(10^{-7}\frac{mole}{L}\right)\left[550\frac{mg\,H_2S}{L}\right]\left(33.07\frac{g\,HS^-}{mole}\right)}{\left[10^{-6.5}\frac{mole}{L}\right]\left(34.08\frac{g\,H_2S}{mole}\right)} = 169\frac{mg}{L}$$

$$C_{water}^{HS^-} = \frac{(K_{a1})\left(C_{water}^{H_2S}\right)\left(33.07\frac{g\,HS^-}{mole}\right)}{\left[10^{-pH}\frac{mole}{liter}\right]\left(34.08\frac{g\,H_2S}{mole}\right)} = \frac{\left(10^{-7}\frac{mole}{L}\right)\left[641\frac{mg\,H_2S}{L}\right]\left(33.07\frac{g\,HS^-}{mole}\right)}{\left[10^{-6.5}\frac{mole}{L}\right]\left(34.08\frac{g\,H_2S}{mole}\right)} = 197\frac{mg}{L}$$

The mass of hydrosulfide ion in 11,650 barrels of produced water would equal about 685 pounds to 798 pounds at pH 6.5, 2161 pounds to 2519 pounds at pH 7, and 6834 pounds to 7967 pounds at pH 7.5.

$$Mass_{water}^{HS^-} = \frac{\left(11{,}650\frac{bbl}{day}\right)(42\,gal)\left(3.78541\frac{L}{gal}\right)\left(169\frac{mg}{L}\right)}{\left(453.59\frac{g}{lb}\right)\left(1000\frac{mg}{g}\right)} = 684.5\frac{lb}{day}$$

$$Mass_{water}^{HS^-} = \frac{\left(11{,}650\frac{bbl}{day}\right)(42\,gal)\left(3.78541\frac{L}{gal}\right)\left(197\frac{mg}{L}\right)}{\left(453.59\frac{g}{lb}\right)\left(1000\frac{mg}{g}\right)} = 797.7\frac{lb}{day}$$

The total sulfide mass per day on October 26, 2019, would be 2931 pounds (2246 pounds hydrogen sulfide plus 685 pounds hydrosulfide ion) to 3416 pounds (2618 pounds hydrogen sulfide plus 798 pounds hydrosulfide ion) at pH 6.5, 4407 pounds to 5237 pounds at pH 7, and 9081 pounds to 10585 pounds at pH 7.5.

III.7.   Foster Field Reaction-Contingency Plan

The high concentrations of hydrogen sulfide and hydrosulfide ion in the produced water along with the large volume of produced water handled indoors at the facility, posed an extremely hazardous situation due to the toxicity of hydrogen sulfide.   The *Foster Field Reaction-Contingency Plan* contains a CAMEO (Computed Aided Management of Emergency Operations) chemical data sheet dated 09/07/98, which provides that hydrogen sulfide is extremely hazardous with a National Fire Protection Association (NFPA) health rating of 3, extremely flammable with a NFPA flammability rating of 4, and reactive with a NFPA reactivity rating of 3.[32] The health and flammability NFPA ratings for hydrogen sulfide are consistent with those given in a 1975 NFPA publication[33]; however, the reactive rating in the NFPA publication is given as 0. A recently accessed CAMEO chemical data sheet for hydrogen sulfide gives a NFPA health rating of 4, a flammability rating of 4, and reactive/instability rating of 0.[34] A NFPA health rating of 4 means lethal, and a rating of 3 means extremely dangerous. The plan categorizes hydrogen sulfide releases as a potentially hazardous volume, an eminently hazardous volume, and a not-potentially hazardous volume. The plan does not give specific volumes of hydrogen sulfide for the categories. However, the scope references operations involving hydrogen sulfide that are subject to the provisions of Statewide Rule 36.

Texas Administrative Code (TAC) Title 16 Part 1 Chapter 3 Rule §3.36[35] mandates various measures concerning hydrogen sulfide safety at oil and gas operations.   Applicability of the mandates is predicated on the 100 ppm and 500 ppm radiuses of exposure (ROE) calculated from the concentration of hydrogen sulfide in the gas and the maximum volume (Q) of gas available to be released either intentionally or accidently in a day. The equations for the calculation are based on the Pasquill-Gifford equation modeling dispersion as a Gaussian plume and are given below.

$$\left(x_{100\,ppm}, ft\right) = \left((1.589)\,(mole\;fraction\;H_2S)(\,Q)\right)^{0.6258}$$

$$\left(x_{500\,ppm}, ft\right) = \left((0.4546)\,(mole\;fraction\;H_2S)(\,Q)\right)^{0.6258}$$

---

[32] Foster Field Reaction-Contingency Plan, Ector County, Texas, February 11, 2003, AGH-OPER-0003017 to AGH-OPER-0003084 at AGH-OPER-0003034.   AGH_0000880 to AGH_0000947 at AGH_0000897.   AGH_0001580 to AGH_0001647 at AGH_0001597.   AGH_0004997 to AGH_0005064 at AGH_0005014.

[33] Hazardous Chemical Data 1975, NFPA No. 49, National Fire Protection Association, 470 Atlantic Avenue, Boston, MA. pp 49-174 to 49-175.

[34] CAMEO Chemicals version 2.7.1 rev 3. Chemical Datasheet, Hydrogen Sulfide. National Oceanic and Atmospheric Administration. https://cameochemicals.noaa.gov/chemical/3625

[35] Texas Administrative Code Title 16. Economic Regulation Part 1. Railroad Commission of Texas Chapter 3. Oil and Gas Division. 3.36 Oil, Gas, or Geothermal Operation in Hydrogen Sulfide Areas. AGH-OPER-0003293 to AGH-OPER-0003300.
https://texreg.sos.state.tx.us/public/readtac$ext.TacPage?sl=R&app=9&p_dir=&p_rloc=&p_tloc=&p_ploc=&pg=1&p_tac=&ti=16&pt=1&ch=3&rl=36

Rule 36[36] requires the facility to measure the hydrogen sulfide concentration of the gas using analytical methods prescribed in the rule and to estimate the gas the volume. The *Foster Field Reaction Contingency Plan* contains a "Certificate of Compliance Statewide Rule 36" for Aghorn Operating Inc., for the Foster D facility, dated 3/31/1997, giving a hydrogen sulfide concentration of 110,000 ppm and a maximum escape volume of 45 MCF (45,000 cubic feet) with radiuses of exposure of 274 feet for 100 ppm and 126 feet for 500 ppm.[37] This same information is given on a "Certificate of Compliance Form H-9" for Aghorn Operating Inc., for the Foster D facility, dated 3/31/1997.[38] The following shows the calculation of 274 foot (ft) distance with the substitution of this concentration, volume, and various conversion factors in the Pasquill-Gifford equation, given above, for the 100 ppm radius

$$\left(x_{100\,ppm}, ft\right) = \left((1.589)\left(\frac{110,000\,ppm}{1,000,000\frac{ppm}{mole\,fraction}}\right)(45\,MCF)\left(1000\frac{ft^3}{MCF}\right)\right)^{0.6258}$$

$$\left(x_{100\,ppm}, ft\right) = \left((1.589)(0.11\,mole\,fraction)(45,000\,ft^3)\right)^{0.6258} = 274\,ft$$

A gas volume of 45,000 cubic feet is equal to 8,015 barrels, which closely approximates the total volume of the 3,000-barrel suction tank and 5,000-barrel overflow tank.

$$Volume = \frac{(45,000\,ft^3)\left(7.48052\frac{gal}{ft^3}\right)}{\left(42\frac{gal}{bbl}\right)} = 8014.8\,bbl$$

This volume of gas with a hydrogen sulfide concentration of 110,000 ppm would equal 444 pounds of hydrogen sulfide.

$$n = \frac{VP}{RT} = \frac{(0.11\,atm)(45,000\,ft^3)\left(28.3168\frac{L}{ft^3}\right)\left(34.08\frac{g}{mol}\right)}{\left(0.082057\frac{L\,atm}{mol\,K}\right)(288.71K)\left(453.59\frac{g}{lb}\right)} = 444\,lb$$

---

[36] Statewide Rule 36, Hydrogen Sulfide Safety, Oil & Gas Division, Railroad Commission of Texas, revised May 2012. AGH-OPER-0000659 to AGH-OPER-0000728.

[37] Foster Field Reaction-Contingency Plan, Ector County, Texas, February 11, 2003, AGH-OPER-0003017 to AGH-OPER-0003084 at AGH-OPER-0003055. AGH_0000880 to AGH_0000947 at AGH_0000918. AGH_0001580 to AGH_0001647 at AGH_0001618. AGH_0004997 to AGH_0005064 at AGH_0005035.

[38] Railroad Commission of Texas, Oil and Gas Division, Certificate of Compliance Statewide Rule 36, Form H-9, Operator: Aghorn Operating, Inc., Name of Lease, Facility or Operation: Foster "D", approved March 31, 1997, AGH-OPER-0003176 or AGH-OPER-0003177.

Another "Certificate of Compliance Statewide Rule 36 Form H-9" for Aghorn Operating Inc., for the Foster D facility, dated 1/17/12, gives a hydrogen sulfide concentration of 96,000 ppm and the maximum escape volume of 55 MCF with radiuses of exposure of 285 feet for 100 ppm and 130 feet for 500 ppm.[39] The following shows the calculation of 130 ft distance with the substitution of this concentration, volume, and various conversion factors in the Pasquill-Gifford equation, given above, for the 500 ppm radius

$$\left(x_{500\,ppm}, ft\right) = \left((0.4546)\left(\frac{96,000\,ppm}{1,000,000\frac{ppm}{mole\,fraction}}\right)(55\,MCF)\left(1000\frac{ft^3}{MCF}\right)\right)^{0.6258}$$

$$\left(x_{500\,ppm}, ft\right) = \left((0.4546)(0.096\,mole\,fraction)(55,000\,ft^3)\right)^{0.6258} = 130\,ft$$

Item 21 of the H-9 form is "The 100 ppm ROE includes any part of a public area except a public road," and the "Yes" box is checked. Item 22 of the form is "The 500 ppm ROE includes any part of a public road," and the "Yes" box is checked. Therefore, the facility is subject to Rule 36 requirements to safeguard the public from the harmful effects of the facility's hydrogen sulfide released either intentionally or accidentally. This means the release of hydrogen sulfide into the ambient air at concentrations that may pose endangerment to the public was considered feasible by the state of Texas.

A volume of hydrogen sulfide considered a potential hazard is set forth in Rule 36, which uses an ROE of 50 feet for 100 ppm as requiring the fewest provisions. A hydrogen sulfide emission of 1.22 pounds per hour gives a 100 ppm ROE of 50 feet. A mass of 1.22 pounds of hydrogen sulfide would be present in 228 gallons to 266 gallons of the produced water. Smaller volumes of produced water would contain 1.22 pounds of total sulfide.

$$\frac{\left(1.22\frac{lb}{hr}\right)(11650\,bbl)\left(42\frac{gal}{bbl}\right)}{(2246\,lb)} = 265.8\frac{gal}{hr}$$

$$\frac{\left(1.22\frac{lb}{hr}\right)(11650\,bbl)\left(42\frac{gal}{bbl}\right)}{(2618\,lb)} = 228.0\frac{gal}{hr}$$

Hydrogen sulfide has a flammable range of 4.3% to 46%. Below 4.3%, the mixture in air is too lean to burn and above 46%, the mixture in air is too rich to burn. The hydrogen sulfide

---

[39] Railroad Commission of Texas, Oil and Gas Division, Certificate of Compliance Statewide Rule 36, Form H-9, Operator: Aghorn Operating, Inc., Name of Lease, Facility or Operation: Foster "D", approved January 17, 2012, AGH-OPER-0003179 or AGH-OPER-0003180.

concentrations reported on the Form H-9 by Aghorn Operating Inc, of 96,000 ppm and 110,000 ppm are equal to 9.6% and 11% and fall in the flammable range of above 4.3% and below 46%. Hence, the hydrogen sulfide causes the gas to pose an endangerment due to flammability. Hydrogen sulfide has an NFPA flammability rating of 4, which is an EPA criterion for an extremely flammable substance.

IV.   RELEASE TO AMBIENT AIR

IV.1.   Presence of an Extremely Hazardous Pollutant

Release of an extremely hazardous substance, hydrogen sulfide, to the ambient air at concentrations that posed a threat to human health was evidenced by measurements made with the hydrogen sulfide monitors of Jacob Dean and the Odessa Fire Department. Confirmatively, measurements made by OSHA involving hydrogen sulfide monitors, gas chromatography coupled to mass spectrometry, colorimetric indicator tubes, and ion chromatography, showed the presence of hydrogen sulfide at high concentrations in air contacted by the produced water and in the produced water-soaked clothing of the deceased. Consistently, measurements provided by Aghorn show high concentrations of hydrogen sulfide in the produced gas and water at the Foster D facility.

IV.2.   Ambient Air

The chemistry of hydrogen sulfide, the measured hydrogen sulfide concentrations of the produced gas and water, and the dispersion and dilution of hydrogen sulfide in the outside air provide that hydrogen sulfide was released into ambient air at concentrations that pose a threat to human health based on the circumstances of the release incident.

Prediction of the dispersion and dilution of the released hydrogen sulfide into the ambient air is facilitated by an estimate of the release rate of hydrogen sulfide. The release rate of hydrogen sulfide is related to the leak rate of the produced water as the hydrogen sulfide is evolved from the produced water into air. The leak rate is the volume of produced water over time; hence, an estimate of the volume of produced water is needed. The duration would be the time at the beginning of the leak to the time that the leak volume is estimated. The mass release rate of the hydrogen sulfide would be the product of the hydrogen sulfide concentration and the leak rate of the produced water.

IV.3.   Produced Water Spill Volume Estimates

The Odessa Fire Department incident report (AGH-OPER-0000613, AGH-OPER-0000625, or AGH-OPER-0000748) states that there was 2-3 inches of produced water throughout the building and the building dimensions were approximately 100 feet by 25 feet. Dimensions of 91 feet by 25 feet were measured using Google Maps™. The volume of produced water on the floor in the building would be about 2,836 gallons at a 2-inch depth and 4,254 gallons at a 3-inch depth.

$$V_{floor}^{2-inch} = (91\,feet)(25\,feet)\left(\frac{2\,inch}{12\frac{inch}{foot}}\right)\left(\frac{28.3168\frac{liter}{cubic\,feet}}{3.78541\frac{liter}{gallon}}\right) = 2,836\,gallon$$

$$V_{floor}^{3-inch} = (91\,feet)(25\,feet)\left(\frac{3\,inch}{12\frac{inch}{foot}}\right)\left(\frac{28.3168\frac{liter}{cubic\,feet}}{3.78541\frac{liter}{gallon}}\right) = 4,254\,gallon$$

The County of Ector Sheriff's Office drone video[40, 41], the Odessa Fire Department video[42, 43], and aerial images[44] show a large area of spilled produced water. As shown in the image of Figure 2, to the south, pooling extended west, past the 5,000-barrel tank to approximately 70% of the width between the east and west perimeter fencing. As shown in the image of Figure 3, wetted ground and pooling occurred from the north door around to the north side of building to the west side of the building. This area was estimated from Google Maps™ to be approximately 18 feet wide and 83 feet length. The area wetted or pooled with produced water east of the building below the north opening in the perimeter fence to the south opening in the fence was estimated to be approximately 32 feet wide and 239 feet. The area wetted or pooled with produced water south of the fencing opening to the south fence line and east past the 5,000-barrel tank was estimated to be approximately 78 feet wide and 193 feet long.

---

[40] County of Ector Sheriff's Office, Information Industrial Accident, AGH-OPER-0003485 to AGH-0003492 at AGH-OPER-0003491.
[41] QuickTime Movie, AGH-OPER-0003493.
[42] Odessa Fire Department Incident Report, October 27. 2019, AGH-OPER-0004430 to AGH-4467 at AGH-OPER-4446.
[43] MP4 Video, AGH_0003934
[44] Images. AGH-OPER-0003601, AGH-OPER-0003602, AGH-OPER-0003603, AGH-OPER-0003604, and AGH-OPER-0003605.

Figure 2 The morning of October 27, 2019 image of spilled produced water area from AGH-OPER-0003605.

Figure 3 The morning of October 27, 2019 image of spilled produced water area from AGH-OPER-0003602.

The estimated total area (A) of produced water saturated soil would be 24,196 square feet.

$$A = (18 \, feet)(83 \, feet) + (32 \, feet)(239 \, feet) + \; (78 \, feet)(193 \, feet)$$

$$A = 1,494 \, square \, feet + 7,648 \, square \, feet + 15,054 \, square \, feet = 24,196 \, square \, feet$$

This area represents about 30% of the total area within the perimeter fence minus the areas of the buildings and tanks.

$$A_{total} = (260\,feet)(260\,feet) + (93\,feet)(200\,feet) = 86{,}200\,square\,feet$$

$$A_{buildings} = (25\,feet)(93\,feet) + (23\,feet)(23\,feet) = 2{,}804\,square\,feet$$

$$A_{tanks} = \pi r^2 = (3.1416)\left(\frac{30\,feet}{2}\right)^2 + (3.1416)\left(\frac{40\,feet}{2}\right)^2 = 1{,}964\,square\,feet$$

$$\left(\frac{24{,}196\,square\,feet}{86{,}200\,square\,feet - 2{,}804\,square\,feet - 1{,}964\,square\,feet}\right)(100\%) = 29.6\%$$

The estimated total surface volume of the spill outside would be 30,166 gallons at a depth of 2 inches and 45,250 gallons at a depth of 3 inches.

$$V_{surface}^{2-inch} = (24{,}196\,square\,feet)\left(\frac{2\,inch}{12\,\frac{inch}{foot}}\right)\left(\frac{28.3168\,\frac{liter}{cubic\,feet}}{3.78541\,\frac{liter}{gallon}}\right) = 30{,}166\,gallons$$

$$V_{surface}^{3-inch} = (24{,}196\,square\,feet)\left(\frac{3\,inch}{12\,\frac{inch}{foot}}\right)\left(\frac{28.3168\,\frac{liter}{cubic\,feet}}{3.78541\,\frac{liter}{gallon}}\right) = 45{,}250\,gallons$$

The ground beneath the pooled standing water would hold a considerable volume of water. Assuming a moderate basic infiltration rate of 0.59 inch per hour to 1.97 inches per hour[45, 46] for an average duration of 7.5 hours gives a saturation of 4.43 inches to 14.76 inches. With a void volume of 50%, the comparable water depth would be 2.21 inches to 7.38 inches. The volume of water in the 24,196 square feet of saturated soil would be 33.334 gallons at 2.21 inches and 111,314 gallons at 7.38 inches.

$$V_{subsurface}^{2.21-inch} = (24{,}196\,square\,feet)\left(\frac{2.21\,inch}{12\,\frac{inch}{foot}}\right)\left(\frac{28.3168\,\frac{liter}{cubic\,feet}}{3.78541\,\frac{liter}{gallon}}\right) = 33{,}334\,gallons$$

$$V_{subsurface}^{7.38-inch} = (24{,}196\,square\,feet)\left(\frac{7.38\,inch}{12\,\frac{inch}{foot}}\right)\left(\frac{28.3168\,\frac{liter}{cubic\,feet}}{3.78541\,\frac{liter}{gallon}}\right) = 111{,}314\,gallons$$

---

[45] Tidemann, C. 1996. Infiltration rate. Geo Learning. Freie Univ., Berlin. https://www.geo.fu-berlin.de/en/v/geolearning/glossary/infiltration_rate.html.

[46] Johnson, A. A Field Method for Measurement of Infiltration, General Ground-Water Techniques, Geological Survey Water Supply Paper 1544-F, U.S. Geological Survey, 1991. p F-7, Table 1. https://pubs.usgs.gov/wsp/1544f/report.pdf.

NEICRP1899X01

Lowry Expert Report
Page 24 of 44

Aghorn Energy
Ector County, Texas

AGH-OPER-0049371

The image in Figure 4 shows that much of the water had infiltrated or evaporated by late morning on October 28, 2019.

Figure 4 Late morning October 28, 2019 image of spilled produced water area from AGH-OPER-0003623.

As summarized in Table 1, the estimated total volume of spilled produced water on the morning of October 27, 2019, would be 66,337 gallons to 160,818 gallons.

$$V_{spill} = V_{floor}^{2-inch} + V_{surface}^{2-inch} + V_{subsurface}^{2.21-inch} = 2,836 + 30,164 + 33,334 = 66,337 \ gallons$$

$$V_{spill} = V_{floor}^{3-inch} + V_{surface}^{3-inch} + V_{subsurface}^{7.38-inch} = 4,254 + 45,250 + 111,314 = 160,818 \ gallons$$

Table 1 Estimated produced water spill areas and volumes.

Area	Width feet	Length feet	Area square feet	Depth feet	Volume gallon	Depth feet	Volume gallon
Building floor	25	91	2,275	0.167	2,836	0.250	4,255
North outdoor spill	18	83	1,494	0.167	1,863	0.250	2,794
East outdoor spill	32	239	7,648	0.167	9,535	0.250	14,303
South outdoor spill	78	193	15,054	0.167	18,769	0.250	28,153
Subtotal					33,003		49,504
Soil infiltration			24,196	0.184	33,334	0.615	111,314
Total					66,337		160,818

IV.4.   Produced Water Spill Rate Estimates

From October 26, 2019, 6:30 PM to October 27, 2019, 9:30 AM is 15 hours, which together with the estimated total volume of about 66,337 gallons to 160,818 gallons gives an estimated leak rate of 4,422 gallon per hour (73.7 gallons per minute) to 10,721 gallons per hour (178.7 gallons per minute). Table 2 provides a summary of the components for the estimated leak rate.

Table 2 Estimated produced water leak rate

Parameter	Unit	2 inch depth	3 inch depth
Building floor area volume	gallon	2,836	4,255
Outdoor spill area volume	gallon	30,166	45,250
Infiltration rate	inch per hour	0.590	1.970
Infiltration duration	hour	7.5	7.5
Infiltration area volume	gallon	33,334	111,314
Volume sum	gallon	66,337	160,818
Leak Duration	hour	15	15
Leak rate	gallon per hour	4,422	10,721
Leak rate	gallon per minute	73.7	178.7

Both the drone and fire department videos show, through the south bay door, produced water cascading out of the end of the pump plunger chamber onto the floor. The cascading section was approximately 18 inches wide falling about 42 inches (chest high). The width was estimated from National Quintuplex plunger pump drawings.[47, 48 49] The height was estimated from the YouTube video.[50] The cascading water was reminiscent of a rectangular weir, which is used to measure the flow rate of water. The general equation and the Francis formula for a suppressed rectangular weir are given below,

$$Q = \frac{2}{3} c_d b (2g)^{0.5} h^{1.5} = 3.33(b - 0.2h)h^{1.5}$$

[47] National Oilwell Varco 300Q-5 Quintuplex Plunger Parts List, https://calroc.ca/equipment/media/300Q-5-Quintuplex-Plunger-Pump-Parts-List.pdf
[48] Parts List National Quintuplex Plunger Types J-250-L, J-250-M, J-250-H, https://inventory.powerzone.com/invimages/59315/spec-oem-national-j250.pdf
[49] Permian Pump & Power, LLC, National 300Q-5 J-275 Quint Pump and Parts Specification https://www.permianpumpandpower.com/national-300q5-j275-quint-pump-and-parts-specifications
[50] At about 3:24 minutes of the YouTube video.

AGH-OPER-0049373

where Q is the flow, c_d is the discharge coefficient constant for the weir, b is the width of the weir, g is gravitational acceleration, and h is the elevation head on the weir.[51] The Francis formula is in a form for Imperial units. Substitution of 18 inches for the width of the weir and 1.25 inches for the head on the weir gives a flow of 74.3 gallons per minute.

$$Q = 3.33 \left(\left(\frac{18\ inch}{12\ \frac{inch}{foot}} \right) - 0.2 \left(\frac{1.25\ inch}{12\ \frac{inch}{foot}} \right) \right) \left(\frac{1.25\ inch}{12\ \frac{inch}{foot}} \right)^{1.5} = 0.167\ \frac{cubic\ feet}{minute}$$

$$Q = \left(0.167\ \frac{cubic\ feet}{minute} \right) \left(28.3168\ \frac{liter}{cubic\ feet} \right) \left(3.78541\ \frac{gallon}{liter} \right) = 74.3\ \frac{gallon}{minute}$$

Increasing the head on the weir from 1.25 inches to 2.26 inches gives a calculated leak rate of about 179 gallons per minute.

The YouTube video and an image (Figure 5) show the sides of the plunger chamber to be a couple of inches higher than the ends of the chamber, which is consistent with creating a head causing spillage out the ends of the chamber.

Figure 5 Pump #1 plunger chamber AGH-OPER-0016041.

---

[51] Water Measurement Manual, A Water Resources Technical Publication, United States Department of Interior, Bureau of Reclamation, Third Edition 1997 Revised Reprint 2001. https://www.usbr.gov/tsc/techreferences/mands/wmm/chap07_09.html

If produced water was overflowing at both ends of the plunger chamber and the weir width is taken as 36 inches and the head as 0.78 inches and 1.41 inches, the calculated leak rate would be about 74 gallons per minute and 179 gallons per minute, respectively.

$$Q = 3.33\left(\left(\frac{36\ inch}{12\frac{inch}{foot}}\right) - 0.2\left(\frac{1.41\ inch}{12\frac{inch}{foot}}\right)\right)\left(\frac{1.41\ inch}{12\frac{inch}{foot}}\right)^{1.5} = 0.399\frac{cubic\ feet}{minute}$$

$$Q = \left(0.399\frac{cubic\ feet}{minute}\right)\left(28.3168\frac{liter}{cubic\ feet}\right)\left(3.78541\frac{gallons}{liter}\right) = 179\frac{gallons}{minute}$$

Hence, the estimated leak rate of 74 gallons per minute to 179 gallons per minute can be calculated from the weir equation using weir lengths and heads consistent with the plunger chamber design.

An Aghorn daily metering record shows that on October 26, 2019, 11,650 barrels of produced water was injected over a period of 21.6 hours.[52] The pump flow rate would be about 378 gallons per minute. If two pumps were used, then the flow rate would be 189 gallons per minute for a single pump. This single-pump flow rate is in the vicinity of the estimated leak rate of 74 gallons per minute to 179 gallons per minute, which may suggest a dependence on the head of the produced water in the suction tank.

The daily metering record gives 15 feet as the depth of the produced water in the suction tank. Taking the discharge to the pump at 1 foot gives a head of about 14 feet. The Torricelli equation for a flow from a tank through an orifice is,

$$Q = c_d a (2gh)^{0.5}$$

where Q is the flow, c_d is the discharge coefficient constant for the hole in the tank, a is the cross section area of the hole in the tank, g is gravitational acceleration, and h is the head of the produced water in the tank.[53] Solving the equation for the diameter of a hole for a discharge coefficient of 0.6, a head of 14 feet, and flows of 74 gallons per minutes and 179 gallons per minute gives about 1.3 inches and 2 inches, respectively.

$$d = 2\left(\frac{Q}{c_d \pi (2gh)^{0.5}}\right)^{0.5}$$

---

[52] Exhibit "01DOC14", AGH_0002867 to AGH_0002872 at AGH_0002872.
[53] Dachi, R.; Setiawan, I. Measurement of gravitational acceleration with the leak tank method, Journal of Physics: Theories and Applications, 2(1), 19-26, 2018.

The Chemical Safety Board said the damaged pump plunger was the likely release point of the produced water.[54] According to part invoices for pump #1[55], the plunger had a diameter of 3.5 inches. The plunger bore was about 3 feet above the floor. If the bore for the plunger were limiting the flow, then the calculated flow with a head of 12 feet would be about 500 gallons per minute with a discharge hole diameter of 3.5 inches. Although the flow may have come out of the plunger borehole, an upstream component (pipe, valve, etc.) may have had a smaller orifice limiting the flow.

As the produced water spills out of the tank, the leak rate would decrease because the head decreases. However, if produced water were coming into the tank from the other sites then the leak rate may not decrease with time if a given head were maintained.

If water were not coming into the suction tank, then the applicable tank emptying time equation is,

$$t = \left(\frac{a_t}{c_d a_h}\right)\left(\frac{2h}{g}\right)^{0.5}$$

where t is the emptying time, c_d is the discharge coefficient constant for the hole in the tank, a_t is the cross-section area of the tank, a_h is the cross-section area of the hole, g is gravitational acceleration, and h is the head of the produced water in the tank. The calculated emptying time for the 30-foot diameter suction tank with a head of 12 foot would be about 4.2 hours with a 3.5-inch hole, about 13 hours with a 2-inch hole, and about 52 hours with a 1-inch hole. If the produced water spilled for about 15 hours from the evening of October 26, 2019, to the morning of October 27, 2019, then a hole diameter of 2 inches or smaller was likely limiting.

IV.5.   Hydrogen Sulfide Release

An estimate of the hydrogen sulfide release would be the product of the hydrogen sulfide content of the produced water and the produced water leak rate. Hydrogen sulfide is a gas at ambient temperatures, and, hence, at high aqueous concentration it readily partitions from the water to the ambient air. Along with gas diffusivity, partitioning would be assisted by the turbulence of the flow cascading out of the plunger chamber and the wind disturbance of the surface of the spilled water. With a produced water leak rate of 74 gallons per minute to 179 gallons per minute and a hydrogen sulfide concentration of 550 mg/L to 641 mg/L, the hydrogen sulfide release rate would be about 20 pounds per hour to about 57 pounds per hour.

---

[54] Hydrogen Sulfide Release at Aghorn Operating Waterflood Station, Odessa, Texas, Incident date October 26, 2019, No. 2020-01-1-TX, Factual Update, July 27, 2020, Chemical Safety and Hazard Investigation Board, page 5.
[55] Exhibit "01DOC05" Pump #1, AGH_0003474 to AFH_0003498.

$$\frac{\left(74\,\frac{gallon}{minute}\right)\left(60\,\frac{minute}{hour}\right)\left(3.78541\,\frac{liter}{gallon}\right)\left(550\,\frac{milligram}{liter}\right)}{\left(1000\,\frac{milligram}{gram}\right)\left(453.59\,\frac{gram}{pound}\right)} = 20.38\,\frac{pound}{hour}$$

$$\frac{\left(179\,\frac{gallon}{minute}\right)\left(60\,\frac{minute}{hour}\right)\left(3.78541\,\frac{liter}{gallon}\right)\left(641\,\frac{milligram}{liter}\right)}{\left(1000\,\frac{milligram}{gram}\right)\left(453.59\,\frac{gram}{pound}\right)} = 57.45\,\frac{pound}{hour}$$

IV.6.   Air Dispersion

On October 26, 2019, while walking up the road on the east side of the interior property fence, members of the Odessa Fire Department measured 26 ppm hydrogen sulfide at 8:56 p.m. (20:56) near the south fence opening and 111 ppm hydrogen sulfide at 8:58 p.m. (20:58) near the north opening in the fence.[56, 57]   Further, Jacob Dean's meter recovered from his truck had measured 27 ppm hydrogen sulfide at 6:51 p.m. (18:51). According to data from the weather station at Odessa-Schlemeyer Field, at 6:53 p.m. (18:53) on October 26, 2019, the wind was from the southwest (200 degrees) at 6 miles per hour, and at 8:53 p.m. (20:53) on October 26, 2019, the wind was from the southwest (210 degrees) at 6 miles per hour. [58] Since, measurements of the hydrogen sulfide level in ambient air were made, an air dispersion model can estimate what release was necessary to give the measured ambient air concentrations. The calculated hydrogen sulfide release rates were 20 pounds per hour to 57 pounds per hour. A portion of this hydrogen sulfide remained in the pooled liquid to give the 26 ppm measurement near the south gate. Assuming a proportional relationship between the amounts released and the measured air concentrations would give for a 20 pounds per hour total release, 16.2 pounds per hour for the 111 ppm measurement and 3.8 pounds per hour for the 26-ppm measurement. For a 57 pounds per hour total release, the 111 ppm measurement would be associated with a 46.2 pounds per hour release and the 26 ppm measurement with a 10.8 pounds per hour release.

---

[56] Mark Brown interview, 5/9/2020, EPA CID Investigative Activity Report, AGH-OPER-0010819 to AGH-OPER-0010821.

[57] Microsoft Excel Worksheet, AGH-OPER-0000611

[58] Local Climatological Data, Hourly Observations, October 26, 2019, U.S. Department of Commerce, National Oceanic and & Atmospheric Administration, National Environmental Satellite, Data, and Information Service, National Centers for Environmental Information, Asheville, NC Station: Odessa Schlemeyer Field, TX, US WBAN: 72264803031 (KODO). AGH-OPER-0013093

The weather data was entered into the ALOHA® (Areal Locations of Hazardous Atmospheres) air dispersion model software[59][60] with an estimated release rate. The MARPLOT® (Mapping Application for Response, Planning, and Local Operational Tasks) mapping program was used in the CAMEO® software suite to display ALOHA® threat zone estimates on a Google Maps™ image of the site. Figure 6 shows the threat zones for hydrogen sulfide concentrations greater than 27 ppm and 111 ppm for a ground level 16.2 pounds per hour hydrogen sulfide release from the south bay door of the facility.

Figure 6 MARPLOT® of ALOHA® threat zones of 27 ppm and 111 ppm for a ground level hydrogen sulfide release of 16.2 pounds per hour from the south bay door of the facility with the wind from the southwest (200 degree) at 6 miles per hour at 10 meters.

The modeling indicates a release of 16.2 pounds per hour from the south bay door of the facility could create concentrations of 27 ppm and 111 ppm in the vicinities of the measurements. Air dispersion modeling would predict that a larger release, such as 46.2 pounds per hour, would be capable of creating the measured concentrations. The uncolored areas between the colored lines are the 95% confidence intervals for the locations of the plumes.

---

[59] Jones, R.; Lehr, W.; Simecek-Beatty, D; Reynolds, R.; 2013 ALOHA (Areal Locations of Hazardous Atmospheres) 5.4.4: Technical Documentation. U. S. Dept. of Commerce, NOAA Technical Memorandum NOS OR&R 43.
[60] Other ALOHA® atmospheric inputs: open country, clear, 63 °F, stability class F, 13% humidity, no inversion, and heavy gas calculation.

AGH-OPER-0049378

Figure 7 shows the threat zone for a hydrogen sulfide concentration greater than 26 ppm for a ground level 3.8s pound per hour release from the spilled pooled produced water near the south fence opening.

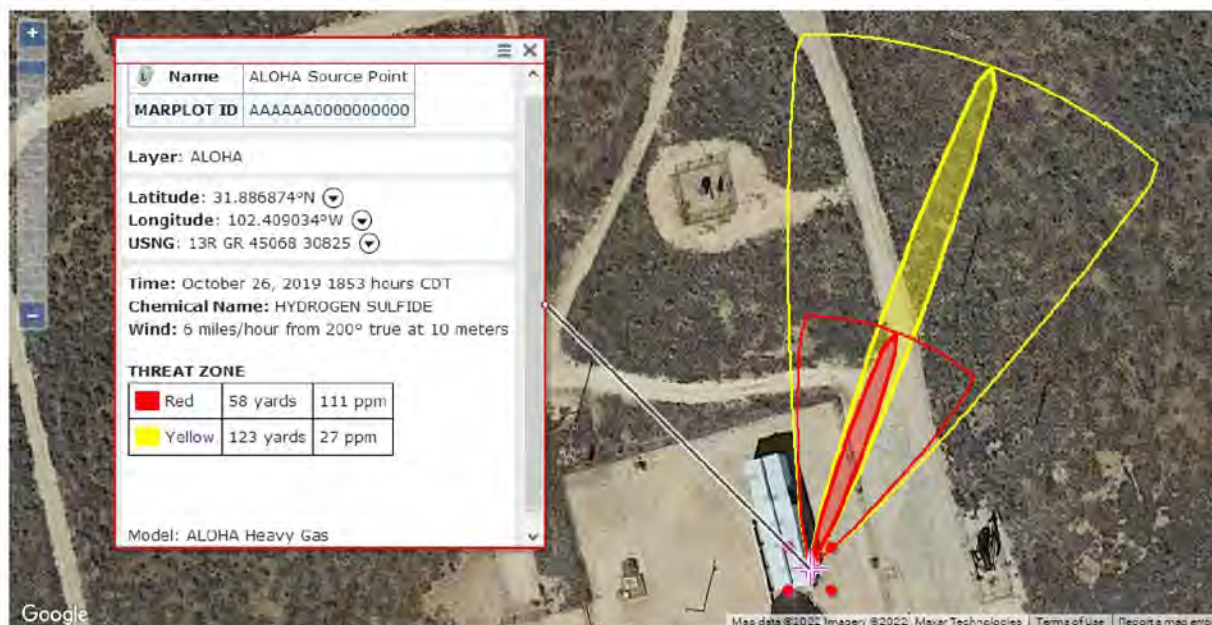**Figure 7 MARPLOT® of ALOHA® threat zone of 26 ppm for a ground level hydrogen sulfide release of 3.8 pounds per hour from spilled pooled produced water near the south fence opening with the wind from the southwest (210 degree) at 6 miles per hour at 10 meters.**

According to the modeling a release of 3.8 pounds per hour from the spilled pooled produced water near the south fence opening could create a concentration of 26 ppm in the vicinity of the measurement. Air dispersion modeling would predict that a larger release, such as 10.8 pounds per hour, would be capable of creating the measured concentration.

Figure 8 shows longer distance treat zones for a 16.2 pounds per hour release from the south bay door of the facility.
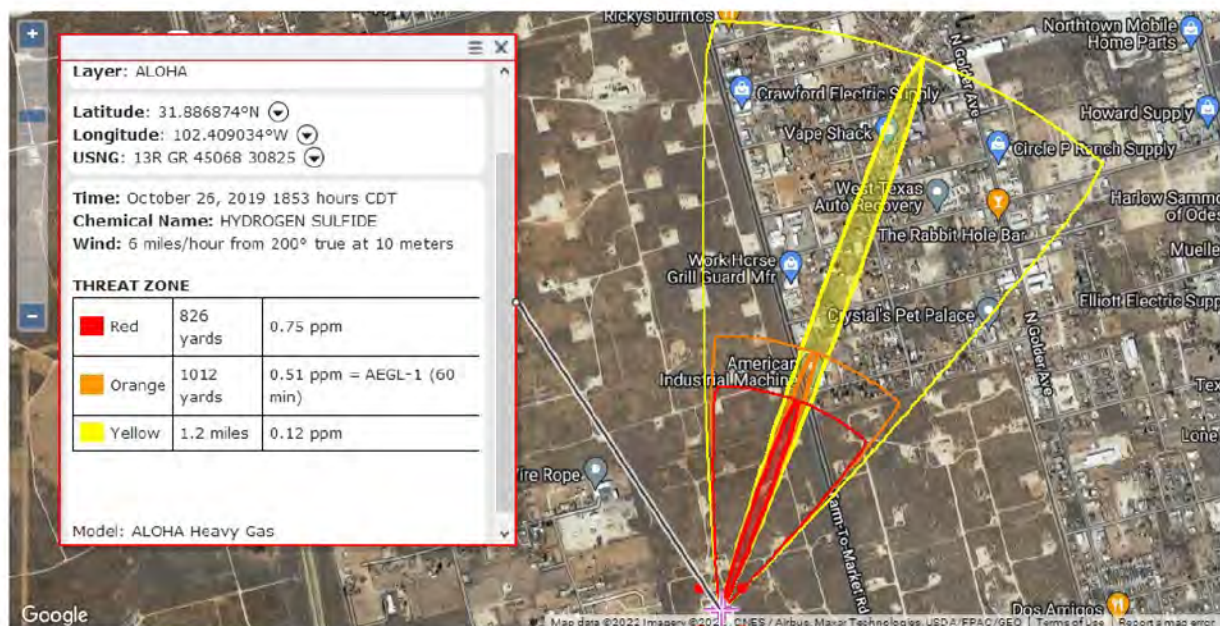
Figure 8 MARPLOT® of ALOHA® threat zones of 0.12 ppm, 0.51 ppm, and 0.75 ppm for a ground level hydrogen sulfide release of 16.2 pounds per hour from the south bay door of the facility with the wind from the southwest (200 degree) at 6 miles per hour at 10 meters.

Figure 9 shows longer distance treat zones for a 46.2 pounds per hour release from the south bay door of the facility.
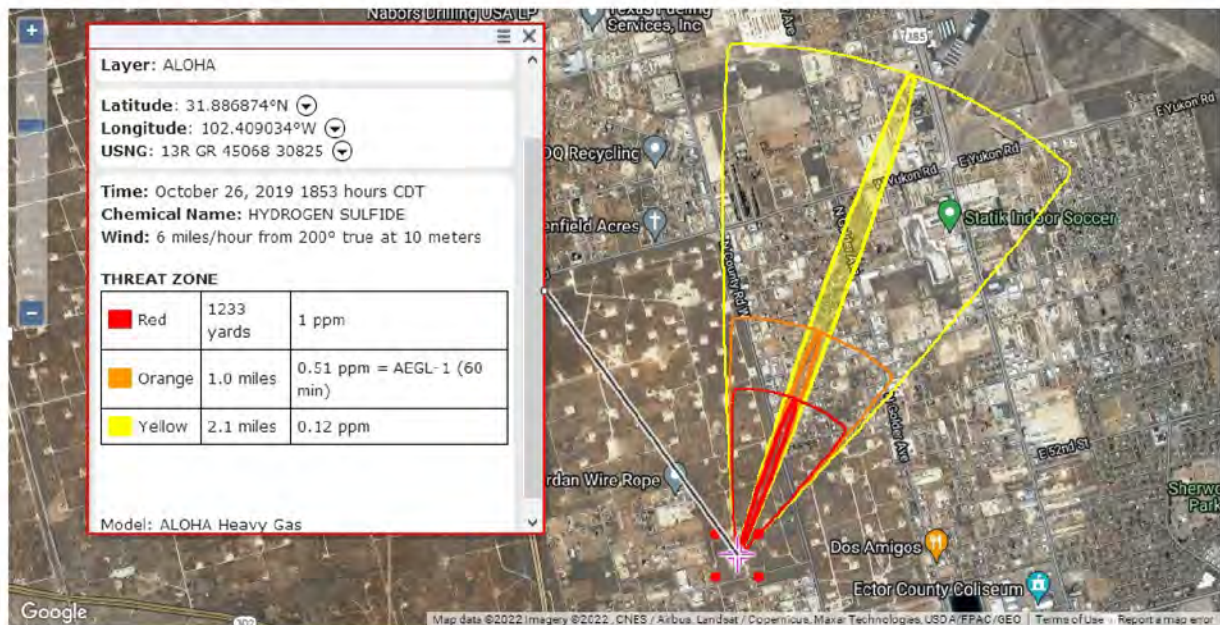
Figure 9 MARPLOT® of ALOHA® threat zones of 0.12 ppm, 0.51 ppm, and 1 ppm for a ground level hydrogen sulfide release of 46.2 pounds per hour from the south bay door of the facility with the wind from the southwest (200 degree) at 6 miles per hour at 10 meters.

AGH-OPER-0049380

For the data in Figures 6 and 8, an exponential fit of the ALOHA® hydrogen sulfide concentration (ppm) with distance (x in feet) for a ground level 16.2 pounds per hour release with a southwest wind at 6 miles per hour gives the following equation.

$$C_{H_2S}^{air}, ppm = 1{,}958{,}400x^{-1.8934} \quad R^2 = 0.9999$$

For a 46.2 pounds per hour release, the following exponential fit was obtained.

$$C_{H_2S}^{air}, ppm = 5{,}862{,}000x^{-1.9072} \quad R^2 = 0.9999$$

Table 3 gives the calculated distance for various hydrogen sulfide health-based levels by rearranging the exponential equations to solve for the distances.

$$x, feet = \left(\frac{C_{H_2S}^{air}, ppm}{1{,}958{,}400} \right)^{\frac{1}{-1.8934}}$$

Table 3 Calculated distances for health-based hydrogen sulfide levels using the exponential fits for the ALOHA® model for ground level sources of 16.2 pounds per hour and 46.2 pounds per hour with a southwest wind at 6 miles per hour at 10 meters.

		16.2 lb/hr	46.2 lb/hr
	H$_2$S	Release	Release
	Level	Distance	Distance
Health Based Level Source	ppm	feet	feet
ATSDR immediate duration minimum risk level	0.02	16,610	27,511
ATSDR acute duration minimum risk level	0.07	8,571	14,264
Texas Administrative Code §112.31 30 minute ambient air level	0.08	7,987	13,299
Texas Administrative Code §112.32 30 minute ambient air level	0.12	6,448	10,752
EPA 8 hour nondisabling acute exposure guideline level	0.33	3,779	6,326
EPA 4 hour nondisabling acute exposure guideline level	0.36	3,609	6,044
EPA 1 hour nondisabling acute exposure guideline level	0.51	3,003	5,035
EPA 0.5 hour nondisabling acute exposure guideline level	0.6	2,756	4,624
EPA 10 minute nondisabling acute exposure guideline level	0.75	2,449	4,113
ACGIH 8 hour time weighed average threshold limit value	1	2,104	3,537
ACGIH 15 minute short term exposure limit	5	899	1,521
OSHA 8 hour time weighted average exposure limit NIOSH 10 minute ceiling recommended exposure limit	10	624	1,058
EPA 8 hour disabling acute exposure guideline level	17	471	801
EPA 4 hour disabling acute exposure guideline level OSHA 10 minute ceiling exposure limit	20	432	735
EPA 1 hour disabling acute exposure guideline level	27	369	628
EPA 8 hour lethality acute exposure guideline level	31	343	584
EPA 0.5 hour disabling acute exposure guideline level	32	337	575
EPA 4 hour lethality acute exposure guideline level	37	312	533
EPA 10 minute disabling acute exposure guideline level	41	296	505
EPA 1 hour lethality acute exposure guideline level OSHA 10 minute peak exposure limit	50	267	455
EPA 0.5 hour lethality acute exposure guideline level	59	244	417
EPA 10 minute lethality acute exposure guideline level	76	214	365
NIOSH immediate dangerous to life and health level	100	185	316

The measured hydrogen sulfide concentrations and the air dispersion modeling concentrations are above various health-based levels, and hence, show a release of an extremely hazardous substance to the ambient air that posed a threat of endangerment to human health.

APPENDIX A: CURRICULUM VITAE FOR JOE H. LOWRY

EDUCATION

1978	Ph.D.[61]	Environmental Health Sciences, University of Michigan, Ann Arbor, MI
1975	M.Sc.[62]	Water Resources Science, University of Michigan, Ann Arbor, MI
1972	B.Sc.	Chemistry, Mathematics, Western Michigan University, Kalamazoo, MI
1970	A.Sc.	Chemistry, Mathematics, Muskegon County Community College, Muskegon, MI

EMPLOYMENT HISTORY

U.S. Environmental Protection Agency, Office of Enforcement and Compliance Assurance, National Enforcement Investigations Center (NEIC) Lakewood, CO

1997-present	Chief Scientist, National Technical Expert
1993-1997	Senior Science Advisor, National Technical Expert
1990-1993	Chemistry Branch Chief, National Technical Expert
1990 (3 mths)	Acting Assistant Director NEIC, Acting Director Office of Laboratory Services, National Technical Expert
1986-1990	Chemistry Branch Chief, National Technical Expert
1984-1986	Inorganic Analytical Chemistry Section Chief, National Technical Expert
1980-1984	Inorganic Analytical Chemistry Section Chief
1978-1980	Chemist

University of Michigan, Rackham Graduate School, School of Public Health, Ann Arbor, MI

1976-1978	Research Assistant for Dr. K.H. Mancy under an EPA Grant entitled "The Development and Application of a Polarographic Membrane Ozone Electrode."
1977 (1 mth)	Instructor and Chemist for Dr. K.H. Mancy at the National Research Center, Cairo, Egypt under an EPA and WHO grant entitled "Water Quality Studies on the River Nile and Lake Nasser."
1974-1976	Research Assistant for Dr. K.H. Mancy under the NOAA Sea Grant Program for "Nutrient Chemistry in Lake Systems."

Anatech Services Inc., Ann Arbor, MI

1975-1977	Chemist and Consultant (part-time) at an analytical services laboratory owned and operated by Dr. William Prater.

Teledyne RRR, Muskegon, MI

1972-1974	Analytical Chemist - Technical Representative at the research laboratory of the Muskegon County Wastewater Spray Irrigation System which was directed by Dr. Y.A. Dimerjian.

---

[61]Dissertation: *The Voltammetric Coelectrodeposition of Selenium (IV) with Copper (II) and Differential Pulse Stripping Trace Level Analysis of Selenium at a Hanging Mercury Drop Electrode.*
[62] Thesis: *The Investigation and Development of an Automated Inorganic and Organic Nitrogen Analyzer.*

AWARDS

USDOJ Raymond W. Mushal Award for Outstanding Contribution to Federal Criminal Law Enforcement (2014)
EPA Bronze Medal for Commendable Service (1984, 1998, 1998, 1999, 2000, 2001, 2014)
EPA Superior Performance Award (1982, 1983, 1987, 1990, 1994, 1996)
EPA Special Act Award (1981, 1985, 1986)
NEIC Mentor Award (2001)
NEIC Director's Award (1990, 1997)
NEIC Superior Accomplishment Award (2005, 2007, 2010, 2011)

ENFORCEMENT / LITIGATION SUPPORT

U.S. v. Louie Sanft, John Sanft, and Seattle Barrel and Cooperage, (2:19-CR-00258-RAJ WD WA), 2021 expert report and testimony.
State of Maryland v. PH Company Inc, and Patrick Haddad, (C-02-CR-19-000877 Anne Arundel County Circuit Court), 2019 expert report.
U.S. v. John H. Couey, (4:19-CR-00059-GHD-JMV ND MS), 2018 expert report.
U.S. v. TAPI Puerto Rico Inc, (3:20-CV-01178), 2018 and 2019 expert reports.
U.S. v. Steven Michael Braithwaite, Adam Thomas Braithwaite, Nebraska Railcar Cleaning Services LLC, (8:18-CR00216-LSC-SMB D NE), 2018 expert report and 2021 sentencing hearing testimony.
U.S. v. Custom Carbon Processing, Inc., Peter Margiotta, and Mark Hurst (CR 17-143-BLG-SPW D MT), 2018 expert reports and 2019 testimony.
State of Ohio v. Environmental Enterprises Inc. and Kyle Matthew Duffens and Gerald E. Nocks (Case No. B1406608) The State of Ohio, Hamilton County Court of Common Pleas, 2017 expert report.
U.S. v. Glenn Welch and Welch Group Environmental (No. 8:2016-CR-00541 D SC), 2016 expert report.
U.S. v. KTX Limited and KTX Properties, Inc (No. 1:16-CR-00075 ED TX), 2016 consultation.
In the Matter of The U.S. Bureau of Reclamation, National Electric Coil, Environmental Contractors, LLC and CT A Construction and Environmental, LLC, Yellowtail Dam Facility, MT (RCRA-08-2015-002), 2016 consultation.
State of California v. Green Compass Environmental Solutions LLC, Santa Clara Waste Water Company, Charles Ray Mundy, Douglas Brian Edwards, Brock Gustin William Baker, Dean William Poe, Mark Stephen Avila, William James Mitzel, Kenneth Douglas Griffin Jr., Marlene Joan Faltemier, David Joseph Wirsing (VSIJIS Case: 2015023881), 2015 expert report, 2015 grand jury testimony, and 2018 expert report.
U.S. v. Louis Daniel Smith, also known as Daniel Smith, also known as Daniel Votino; Karis DeLong, also known as Karis Copper; Tammy Olson; and Chris Olson, (No. 13-CR-14-RMP-1 ED WA), 2015 expert report.
U.S. v. Tier NY, LLC, (No. 14-M-2096 ND NY), 2014 consultation.
U.S. v. New Nautical Coatings, Inc., d/b/a "Sea Hawk Paints," Sea Hawk Refinish Line, Inc., d/b/a "Refinish Line Auto Supplies," Erik Norrie, David Norrie, Jason Revie, and Tommy Craft (No. 1:14-20081-CR-UNGARO(s)(s) SD FL), 2014 expert report.
U.S. v. Mark Pullyblank, William Clements, and Crane-Hogan Structural Systems, Inc. (No. 3:13-CR-198 (TJM) ND NY), 2014 consultation and investigative report.

In The Matter of Westinghouse Electric Co. LLC. Odgen, UT(RCRA-08-2014-003), 2011, 2012 & 2013 consultation and 2012 expert report.

U.S. v. Port Arthur Chemical Company and Environmental Services, LLC, and Matthew L. Bowman (No. 1:12-CR-42 EDTX), 2012 & 2013 consultation, 2013 declaration and Daubert hearing testimony.

U.S. v. Renato Montorsi, Teresina R. Montorsi, and Kennedy Mint, Inc. (No. 1:12-CR-00480 ND OH), 2012 & 2013 consultation.

City of Colton v. American Promotional Events and Related Consolidated Actions, Colton, CA (No. ED CV 09-01864 PSG (SSx) ED CA) [Consolidated with Case Nos. CV 09-6630 PSG (SSx), CV 09-06632 PSG(SSx), CV 09-07501 PSG (SSx), CV 09-07508 PSG (SSx), CV 10-824 PSG(SSx) and CV 05-01479 PSG (SSx)], 2012 consultation and expert report.

U.S. v. We Lend More Inc., Marc Sadi Vogel, and Raul Antonio Gonzalez-Lopez (No. 11 CR 3327-MMA SD CA), 2011 consultation and 2012 declaration.

In The Matter of ChemSolv, Inc. and Austin Holdings-VA, L.L.C., Roanoke, VA (Docket No. RCRA-03-2011-0068), 2011 declaration and 2012 testimony.

U.S. v. Patrick Dooley (2:11 CR-00252-MJP, WD WA), 2011 expert report and 2012 trial testimony.

U.S. v. David Richard Brown and Jerry Wayne Story (No. CR-11-0194-HE WD OK), 2011 consultation.

U.S. v. Aramais Moloian (2:10-CR-20666, ED MI), 2011 consultation.

State of Ohio v. United Oil Recovery Services, Inc. and David Weber (CR2010-06-0952 and CR2010-06-0953 Butler County Common Pleas Court, Hamilton, OH) 2010 investigative report and 2011 trial testimony.

U.S. v. Mace Securities International, Inc., and Jon Goodrich (5:10-CR-00147, D VT), 2010 and 2011 consultation.

U.S. v. Dennis Beetham and D.B. Western, Inc. (09-CR-235-BR, D OR), 2010 consultation.

U.S. v. Michael Nicholson et al. (CV09-1729-PHX-MHN), 2010 expert report.

U.S. v. Andrew Costa (2:09-CR-00744, D UT), 2009 and 2010 consultation.

In The Matter of The Dairy Dozen – Thief River Falls LLP d/b/a Excel Dairy, Thief River Falls, MN (CAA NOV EPA-5-08-MN-23), 2009 consultation.

U.S. v. Kie-Con, Inc. (CR-10 0934 MAG ND CA), 2009 consultation.

U.S. v. Texas Oil and Gathering, Inc. et al (No. 4:07-CR-00466-1 SD TX), 2009 consultation.

U.S. v. Oregon Metallurgical Corporation LLC and TDY Industries LLC (6:13-cv-02188-TC, D OR), 2008 and 2010 compliance reports and 2011, 2012 and 2013 consultation.

In The Matter of Rhodia, Inc., Ramsey, MT(Docket No: RCRA-08-2004-0006), 2008 consultation.

U.S. v. Ken Pap (5:07-CR-04043 ND IA), 2008 consultation.

U.S. v. Keith Rosenblum et al. (2:07-CR-00294 D MN.), 2008 consultation.

In The Matter of International Malting Company, Great Falls, MT (Docket No. CWA-08-2007-0018), 2007 investigative report.

U.S. v. British Petroleum Exploration Alaska Inc., et al. (No. 3:07-CR-00125-RRBD AK), 2007 investigative report and consultation.

U.S. v. Moshe Rubashkin and Sholom Rubashkin(07-CR-00498-2 ED PA), 2006 investigative report.

U.S. v. Luxury Wheels O.E. Plating Inc., and Albert David Hajduk (04-CR-0346, D CO), 2006 expert report.

U.S. v. Greg Street Plating Inc. (06-CR-00081, D NV), 2006 consultation.

U.S. v. Wayne County Airport Authority (06-CR-20300, ED MI), 2005 consultation.

U.S. v. Rhodia Inc. (CR 03-29-BU-DWM D MT), 2004 consultation.

U.S. v. W. R. Grace et al. (CR-05 -0007-DWM D MT), 2004 consultation.

State of Arizona v. Houston Film Labs et al. (CV2003-00416), 2004 expert report.

U.S. v. James M. Knott and Riverdale Mills Corporation (106 F. Supp.2d 174 ED MA), 2004 investigative report.

U.S. v. Tin Products Inc, et al. (No. CR 3:02-563 D. SC), 2003 consultation.

In The Matter of Rhodia, Inc., Ramsey, MT(Docket No. RCRA-8-2000-07 (7003 Order)), 2002 investigative report and consultation.

U.S. v. Magnesium Corporation of America, et al. (No. 2:01-CV-040-B D UT) 2002 compliance report.

U.S. v. Joel Udell, Pyramid Chemical Sales Co., and Nittany Warehouse LP (Criminal Nos. 05-401, 402, and 403 ED PA), 2002 consultation.

U.S. v. Pneumo Abex Corporation et al. (Civil 2-96-CV-27, ED VA), 2002 and 2012 consultation.

In The Matter of Emporia Foundry, Inc., Emporia, VA (Docket No. RCRA-03-2002-0308), 2002 consultation.

In re Safety-Kleen Inc., Deer Trail, CO, 2001 investigative reports.

U.S. v. Clean Harbors Inc., et al. (Civil C1-01-821, SD OH), 2001 investigative report and consultation.

U.S. v. Allegheny Ludlum Corporation (Civil 95-0990 WD PA), 2000 consultation.

U.S. and State of Arizona v. TRW Vehicle Safety Systems, Inc. (Civil 01-0095 PHX VAM and Criminal 01-10-PHX-ROS), 2000 expert report.

U.S. v. WCI Steel Inc. (4;98CV1082, ND OH), 1999 expert report, deposition, and trial testimony.

State of Ohio v. Danny L. Smith (98-CR-1785 – Franklin County Common Pleas Court, Columbus, OH), 1999 expert report.

U.S. v. Allen Elias (D. Idaho, CR No. 98-00070-E-BLW), 1999 Daubert hearing and trial testimonies and 2000 sentencing hearing testimony.

U.S. v. Burlington Northern Railroad, et al. (4:98CR515 CDP, 98-CR-321-WM, and 4:98CR525 ED MO), 1998 consultation.

U.S. v. FMC Corp. (No. C99-296-E-BLW D ID), 1998 consultation.

U.S. v. Helen Kramer et al. (Civil 89-4340 (JBS) D NJ), 1997 investigative report and consultation.

Horsehead Industries, Inc., and Horsehead Resource Development Co., Inc., v. EPA (Civil No. 95-1286 D DC) 1997 investigative report.

Horsehead Industries, Inc., and Horsehead Resource Development Co., Inc., v. EPA (Civil No. 94-1299 D DC) 1996 affidavit.

U.S. and Commonwealth of Pennsylvania v. Horsehead Industries, Inc., and Horsehead Resource Development Co., Inc. (Civil 1:CV-92-0008, MD PA), 1994 investigative report, 1998 expert report and deposition, and 2006 consultation.

U.S. v. Borden Chemicals and Plastics (Civil 94-440-A-3 c/w 94-2492-A-3, MD LA), 1997 expert report.

U.S. v. Frank Fiorillo, Jr., and Art Krueger (CR S-96-116 GEB, ED CA), 1997 expert report and trial testimony.

U.S. v. Noble Cunningham (1:93-CR-316-1-WCO, ND GA and 194F.3d1186 11th Cir 1999 No. 97-9137), 1997 consultation.

In the Matter of Envirosafe Services of Ohio, Inc., Oregon, OH (Docket No. 5-RCRA-97-008) 1997 investigative report and consultation.

U.S. v. Mobil Oil Corporation, Port Mobil Terminal, Staten Island, New York (Civil 96-1432 (JG)), 1996 consultation.

U.S. v. Johnnie James Williams (CR 96-2018-TU TN), 1996 investigative report and consultation.

U.S. v. Timothy J. Sinskey and Wayne Kumm (CR 96-40010-01 and 02, SD SD), 1996 expert report, Daubert hearing and trial testimonies.

U.S. v. GK Technologies, Inc, and Indiana Steel and Wire Co. (Civil IP 90-2122-C-D/G, SD IN), 1996 affidavit.

U.S. v. HCI Chemtech Distribution, Inc., Fred E. Garner, Andre Rober, and Marc W. Peterson (96-00156-01/04-CR-W-2 ED MO), 1996 expert report.

U.S. v. Midwest Alloys Foundry et al. (CR ED MO), 1996 investigative report and consultation.

U.S. v. Boomsnub Corp. (CR95-5129RJB WD WA), 1995 compliance report and consultation.

In The Matter of R.R. Donnelley and Sons, Inc. (Docket No. V-W-004-95), 1995 affidavit.

U.S. v. Quaker State Corp. (Civil No. 93-0196W ND WV), 1995 consultation.

People of the State of Colorado v. Kevin Ray Dockter (Docket No. 94CR1228 CO) 1994 investigative report.

U.S. v. Ketchikan Pulp Company (Civil A95-025CR, D AK), 1993 consultation.

U.S. v. Melody Knitting Mills Inc., Richard Virgil Bates, and Kenneth Arthur Baber (Case No. CR-92-435-RMT), 1993 affidavit and expert reports.

U.S. v. Taylor Lumber and Treating, Inc. (Civil 93-858-JO, D OR), 1992 compliance report.

In re Ross Metals Corp., Memphis, TN (Docket No. 90-03-R), 1991 compliance report.

U.S. v. Sanders Lead Company Inc., et al. (Civil 89-T-1123-N, ND AL), 1991 affidavit.

In re Northwest Enviroservices Inc. (736F Supp. 238 WD WA), 1989 consultation.

U.S. v. John Boyce, et al. (Civil 84168-C(K), ND WV), 1989 affidavit.

In re Envirite Corp., Thomaston, CT (Docket No. I-90-1063), 1989 investigative report.

U.S. and the State of Alabama v. Interstate Lead Company and Diego Maffei (CV-85-H-0823-S, ND AL), 1988 compliance report and trial testimony.

U.S. v. Protex Industries, Inc., et al. (87-CR-115, D CO), 1987 pretrial hearing testimony.

U.S. v. Chem-Wood Treatment Company Inc., and Erie Kitagawa (Criminal 88-00864 D HI), 1987 compliance reports.

U.S. v. Eagle Picher Industries (No. 85-343 D CO), 1984 compliance report.

U.S. v. Nelson Enterprises and Jon Michael Nelson (85-743M D CO), 1986 compliance report and trial testimony.

U.S. v. Robert K. Blackstone and Wendall Wayne Johnson (Criminal 86-00012 and 86-00013 WD WA), 1986 compliance report.

U.S. v. Richard Brown (86-CR-005 D CO), 1985 investigative report.

U.S. v. Kerr McGee et al. (84-0701-CV-W-9 WD MO), 1986 compliance report and consultation.

U.S. v. Texas Discount Gas Co. and Inland Partners (85-0252-C-C ED MO), 1986 compliance report and consultation.

U.S. v. Quemetco, Inc., and RSR Corporation (Civil Action No. 86-6644-RSWL(JRX)), 1986 compliance report.

U.S. v. Operating Industries, Inc., et al. (CD CA), 1986 compliance report.

U.S. v. Layton Brothers Drum Company Inc., et al. (85-CR-174 D CO), 1985 compliance report and grand jury testimony.

U.S. and State of Rhode Island v. Victory Polishing and Plating Company, Inc. (Civil Action No. 85-0157P), 1985 compliance report and consultation.

U.S. v. Frankel Manufacturing Company (Criminal No. 85-224 D CO), 1985 compliance reports.

U.S. and State of California v. J.B. Stringfellow et al. (Civil 83-2501R, CD CA), 1984, 1985, 1986, 1988, 1995 investigative reports and consultation.

U.S. v. Jay Hamburg and Neil Moser (Criminal No. 86-174 and 86-199 D CO), 1985 compliance report.

U.S. v. Shelton Erickson (CR-88-60019-01 WD LA), 1985 compliance report.

U.S. v. Dexter Clark, Lynette Clark and C.J. Mining, Inc., 1984 affidavit.

U.S. v. Seymour Recycling Corporation, et al. (Civil No. IP 80-457 SD IN), 1983 and 1984 investigative reports.

U.S. v. Merlyn Pollock (87-00148-1-CR-W-8 WD MO) ,1984 compliance report.

In re Chemical Waste Management, Inc., Denver, CO (Docket No. VIII-83-5), 1983 investigative report.

U.S. v. Western Processing Co. (Civil Action No C83 252M WD WA), 1983 compliance report.

U.S. v. Chem-Dyne Corp., et al. (Civil Action No C-1-82-840 SD OH), 1983 compliance report.

State of Maryland v. Fairchild Industries, 1983 trial testimony.

State of West Virginia v. Albert Ingram, 1983 compliance report and consultation.

U.S. v. David M. Wirt, et al. (Criminal No. 82-424A ND GA), 1983 compliance report.

U.S. v. Gary R. Van Lom, Eugene F. Tienken, Charles Tuttle, and Drum Recovery, Inc. (No. CR-84-5 D OR), 1983 compliance reports.

U.S. v. George Henry Garson (Criminal 85-00001 ED PA), 1983 compliance report.

U.S. v. Wade (713F.2d 49 3d Cir 1983), 1983 compliance report.

U.S. v. Berlin and Farro Liquid Incineration, Inc., et al. (Civil Action No. 84-CV-8473-FL ED MI), 1982 compliance report.

U.S. v. Lackawanna Refuse Removal, Inc., et al. (Criminal 82-00173 MD PA) and *Commonwealth of Pennsylvania v. Peter Iacavacci, et al.* (Criminal MD PA), 1982 compliance report.

State of Colorado v. Asarco Inc., Globe Plant, Denver, CO (Civil No. 83-C-2383 D CO), 1982 investigative report.

State of California v. Capri Pumping Service (LA Superior Court), 1982 compliance report.

U.S. v. Inserv Inc., Ivan Matula and Graham Nugent (Crim. H-82-206 SD TX), 1982 compliance report and affidavit.

ENVIRONMENTAL FORENSICS

S.W. Sisk and J.H. Lowry, *Evaluation of Lower Lake Leakage to Prickly Pear Creek, ASARCO East Helena Plant, East Helena, Montana*, EPA-330/2-96-007.

J. Lowry and J. Simon, *Lead Isotope Ratios and Content in the Blood of Fourteen Adults, Triumph Mining Site, Triumph, Idaho*, EPA-330/8-94.

M.E. Ketterer and J.H. Lowry, *Hazardous Substances Source Identification Study, Palmerton Zinc CERCLA NPL Site, Carbon County, Pennsylvania*, EPA-330/2-94-029.

PRESENTATIONS AND PUBLICATIONS

E.A. Betterton, J. Lowry, R. Ingamells, and B. Venner, "Kinetics and Mechanism of the Reaction of Sodium Azide with Hypochlorite in Aqueous Solution," *Journal of Hazardous Materials*, 182, 716-722 (2010).

J.J. Orlando, G.S. Tyndall, E.A. Betterton, J.H. Lowry, and S.T. Stegall, "Atmospheric Chemistry of Hydrazoic Acid (HN$_3$): UV Absorption Spectrum, HO Reaction Rate, and Reactions of the N3 Radical," *Environmental Science and Technology*, 39, 1632-1640 (2005).

M.E. Ketterer, J.H. Lowry, J. Simon, K. Humphries, and M.P. Novotnak, " Lead Isotopic and Chalcophile Element Composition in the Environment near a Zinc Smelting-Secondary Zinc Recovery Facility, Palmerton, Pennsylvania, USA," *Applied Geochemistry*, 16, 207-229 (2001).

J. Beihoffer, E. Bour, C. Gibson, J.H. Lowry, J.J. Reschl, and J.L. Seidel, "Identification and Determination of Isomeric Bromo and/or Chloro Substituted 1,3-Dihalo-5,5-dimethylhydantoins Used in Disinfectants and Pesticides," presented at the 210th American Chemical Society National Meeting and Exposition Program, Chicago, Illinois (1995) and *Journal of AOAC International*, 79, 823-828 (1996).

R. Lorenzana, B. Duncan, M. Ketterer, J. Lowry, J. Simon, M. Dawson, and R. Poppenga, *Bioavailability of Arsenic and Lead in Environmental Media*. EPA 910/R-96-002. United States Environmental Protection Agency (1996).

R.M. Lorenzana, J.H. Lowry, M. Dawson, M.E. Ketterer, and J. Simon, "Concomitant Administration of Intravenous 206Pb to Enable Simultaneous Collection of Oral and Intravenous Area-Under-Curve (AUC) Data for Determination of Oral Bioavailability of Lead Containing Soil and Slag in Swine," presented at the Society of Toxicology Annual Meeting, Seattle, WA (1995).

M.L. Siao and J.H. Lowry, "Reactivity Characterization by Differential Scanning Calorimetry," presented at the USEPA Symposium on Waste Testing and Quality Assurance, Washington, DC (1994).

M.E. Ketterer, J.H. Lowry, E.L. Bour, C.L. Lemmon, and J. Simon, "Investigation of Lead Uptake and Bioavailability using Isotopic Tracers and ICP-MS," presented at the Winter Conference on Plasma Spectrochemistry, San Diego, CA (1994)

J.H. Lowry, M.L. Siao, and C.A. Ramsey, "Releasable Cyanide: Dysfunctional Regulation," presented at the USEPA Symposium on Waste Testing and Quality Assurance, Washington, DC (1992).

J. Simon, J.H. Lowry, and C.A. Ramsey, "A Practical Means of Measurement of Purgeable Organic Halides at Low Concentrations by Oxidative Pyrolysis / Coulometric Titration," presented at the USEPA Symposium on Waste Testing and Quality Assurance, Washington, DC (1992).

J.H. Lowry, E.L. Bour, and T.J. Meszaros, "Evaluation of the Draft High Hazard, Multimedia Protocol Versus Historical Database," presented at the USEPA Symposium on Waste Testing and Quality Assurance, Washington, DC (1991).

M.E. Ketterer, J.H. Lowry and C.A. Ramsey, "Prediction of Waste Toxicity through Classification of Indirect Measurements," presented at the 2nd Conference of the International Federation of Classification Societies, Charlottesville, VA (1989) and 31st Rocky Mountain Conference, Denver, CO (1989).

C.A. Ramsey, M.E. Ketterer and J.H. Lowry, "Application of Gy's Sampling Theory to the Sampling of Solid Waste Materials," presented at the USEPA Symposium on Waste Testing and Quality Assurance, Washing, DC (1989) and 7th GeoTech Conference, Denver, CO (1989).

M.L. Siao, J.H. Lowry, and T.J. Meszaros, "The Determination of Cyanide in Environmental Samples by a Midi-Distillation Procedure," presented at the 31st Rocky Mountain Conference, Denver, CO (1989).

J.H. Lowry and D.S. Kendall, "Elemental Constituents of Drum Samples - Applicability of a Molten Alkali Fusion," presented at the USEPA Symposium on Waste Testing and Quality Assurance, Washington, DC (1985)

J.O. Rasmuson, J.H. Lowry, G.W. Mears and J.D. Boyd, "Comparison and Review of Fusion Techniques for Total Metal ICP Analysis of Difficult Samples," presented at the 10th Annual Meeting of the Federation of Analytical Chemistry and Spectroscopy Societies (1983).

D.S. Kendall, J.H. Lowry, E.L. Bour, and T.J. Meszaros, "A Comparison of Trace Metal Determinations in Contaminated Soils by XRF and ICAP Spectroscopies," in Advances in X-ray Analysis, 27 (1983), Proceedings of the 1983 Denver Conference on the Applications of X-Ray Analysis, Plenum Press, NY.

J.H. Lowry, "Analysis of Hazardous Waste Drum Samples for Inorganic Constituents," presented at the USEPA CLP Inorganic Methodology Conference, San Francisco, CA (1983) and USEPA Quality Assurance Workshop, Golden, CO (1983).

J.H. Lowry, T.J. Meszaros, and L. Conlin, "Automated Atomic Absorption Determination of Lead in Gasoline," *Journal of Automated Chemistry*, 4, 112 (1982).

D.D. Nygaard and J.H. Lowry, "Sample Digestion Procedure for Simultaneous Determination of Arsenic, Antimony and Selenium by Inductively Coupled Argon Plasma Emission Spectrometry with Hydride Generation," *Analytical Chemistry*, 54, 803 (1982).

J.H. Lowry, R.C. Ross, and E.L. Bour, "Measurement of Corrosion Rate and EP Toxicity Hexavalent Chromium for RCRA Samples by Voltammetric Techniques," presented at the 183rd American Chemical Society National Meeting, Las Vegas, NV (1982).

J.H. Lowry, R.C. Ross, and T.L. Law, "Inorganic Analytical Screening and Preparation Schemes for the Analysis of Hazardous Waste Samples," presented at the 183rd American Chemical Society National Meeting, Las Vegas, NV (1982).

J.H. Lowry and S.K. Albrink, "Lead in Gasoline Test Procedure," *Federal Register*, 47, 764 (1982).

J.H. Lowry, T.J. Meszaros, and R.C. Ross, "An Automated Procedure for Simultaneously Determining Total Cyanide and Thiocyanate in Industrial Wastewaters," presented at the 23rd Rocky Mountain Conference, Denver, CO (1981).

J.H. Lowry, R.C. Ross and K. Wang, "Practical Experience on the Use of Coupled ICE/IC Systems for the Determination of Anions in Hazardous Waste Samples," presented at the 22nd Rocky Mountain Conference, Denver, CO (1980).

J.H. Lowry, R.C. Ross, and K. Wang, "Ion Chromatographic Analysis of Process and Particulate Emission Samples from Copper Smelters," presented at the 22nd Rocky Mountain Conference, Denver, CO (1980).

J.H. Lowry, T. Meszaros, and L. Conlin, "An Automated Analysis of Lead in Gasoline," presented at the 31st Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Atlantic City, NJ (1980).

R.B. Smart, J.H. Lowry, and K.H. Mancy, "An Analysis for Ozone and Residual Chlorine by Differential Pulse Polarography of Phenylarsine Oxide," Environmental Science and Technology, 13, 89 (1979).

P.A. Nassos, J.H. Lowry, and K.H. Mancy, "Voltammetric Stripping Analysis of Trace Levels of Selenium in Water and Air," presented at the 1st Midwest Water Chemistry Workshop, Madison, WI (1978).

J.H. Lowry, R.B. Smart, and K.H. Mancy, "Differential Pulse Polarography of Phenylarsine Oxide," *Analytical Chemistry*, 50, 1303 (1978).

J.H. Lowry and K.H. Mancy, "A Rapid Automated System for the Analysis of Total Dissolved Organic Nitrogen in Aqueous Solutions," *Water Research*, 12, 471 (1978).

J.H. Lowry, R.B. Smart, and K.H. Mancy, "Polarographic Reduction of Phenylarsine Oxide," *Analytical Letters*, 10, 979 (1977).

J.H. Lowry and R.B. Smart, "A Multicell System for Differential Pulse Stripping Voltammetry at a HMDE," *American Lab*, 8, 47 (1976).